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(54) 3D STACKED PIEZORESISTIVE PRESSURE SENSOR

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G01L 9/00 (2006.01)
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(2013.01); **G01L 9/0042** (2013.01);
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(58) **Field of Classification Search**

CPC G01L 7/00; G01L 7/08; G01L 9/00; G01L
9/0042; G01L 9/0055; G01L 9/06;
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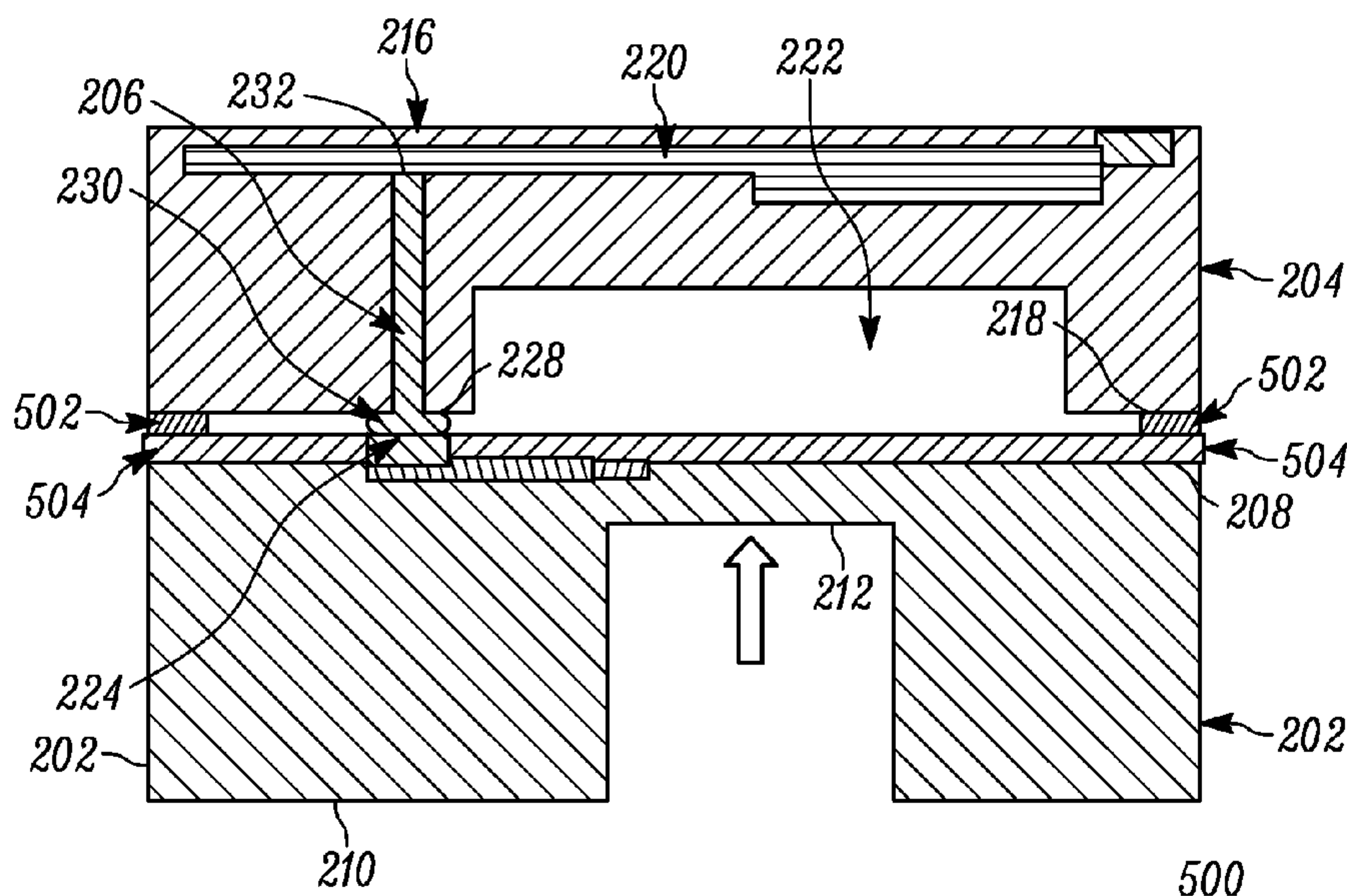
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Primary Examiner — Nguyen Ha

(57) **ABSTRACT**

In a microelectromechanical system (MEMS) pressure sensor, thin and fragile bond wires that are used in the prior art to connect a MEMS pressure sensing element to an application specific integrated circuit (ASIC) for the input and output signals between these two chips are replaced by stacking the ASIC on the MEMS pressure sensing element and connecting each other using conductive vias formed in the ASIC. Gel used to protect the bond wires, ASIC and MEMS pressure sensing element can be eliminated if bond wires are no longer used. Stacking the ASIC on the MEMS pressure sensing element and connecting them using conductive vias enables a reduction in the size and cost of a housing in which the devices are placed and protected.

28 Claims, 15 Drawing Sheets



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	CPC	<i>G01L 9/0055</i> (2013.01); <i>G01L 9/06</i> (2013.01); <i>G01L 19/0076</i> (2013.01); <i>G01L</i> <i>19/0084</i> (2013.01)	2014/0202255	A1 *	7/2014	Niemann G01L 9/08 73/753
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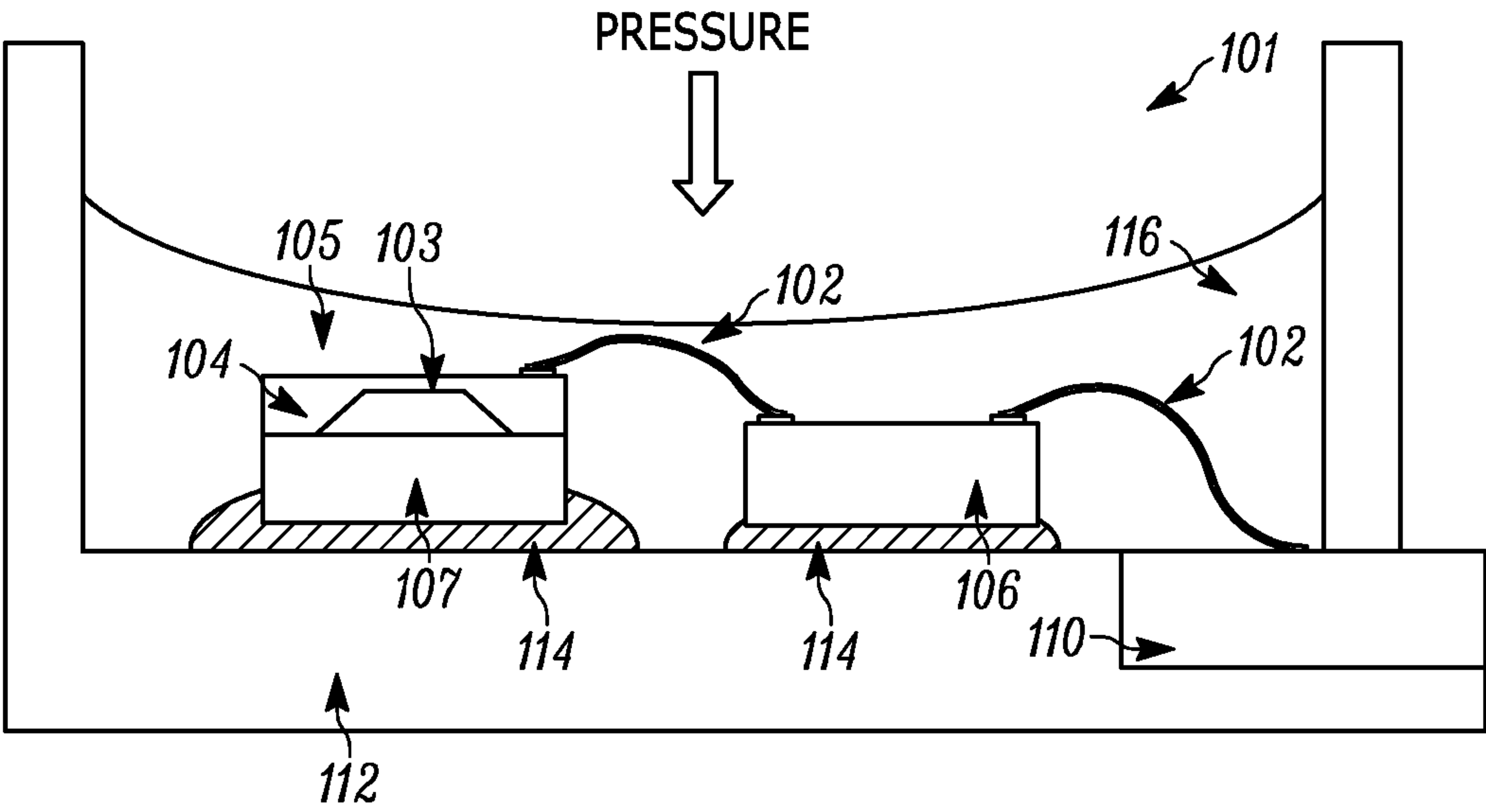
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PRIOR ART 100

FIG. 1

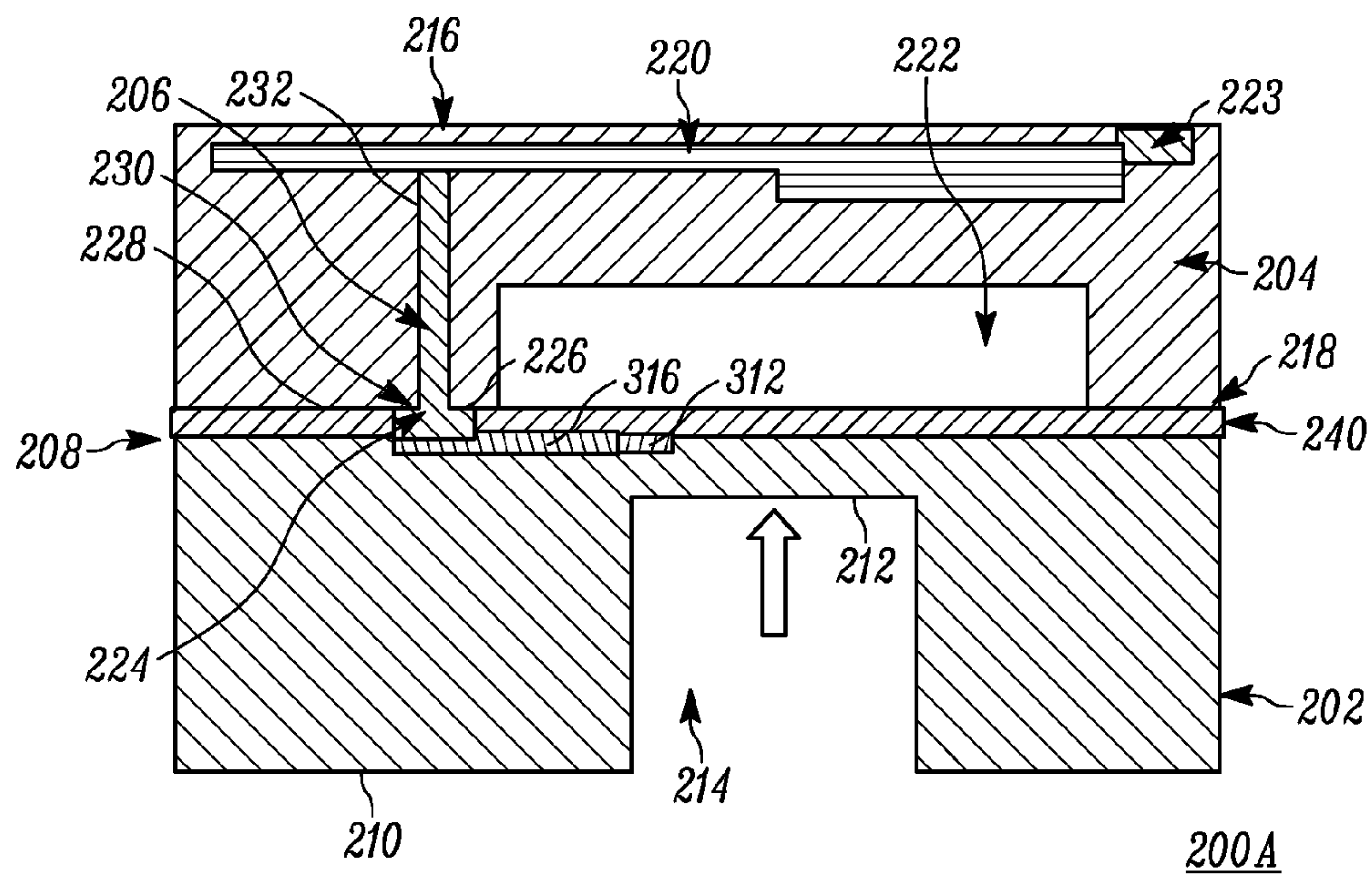


FIG. 2A

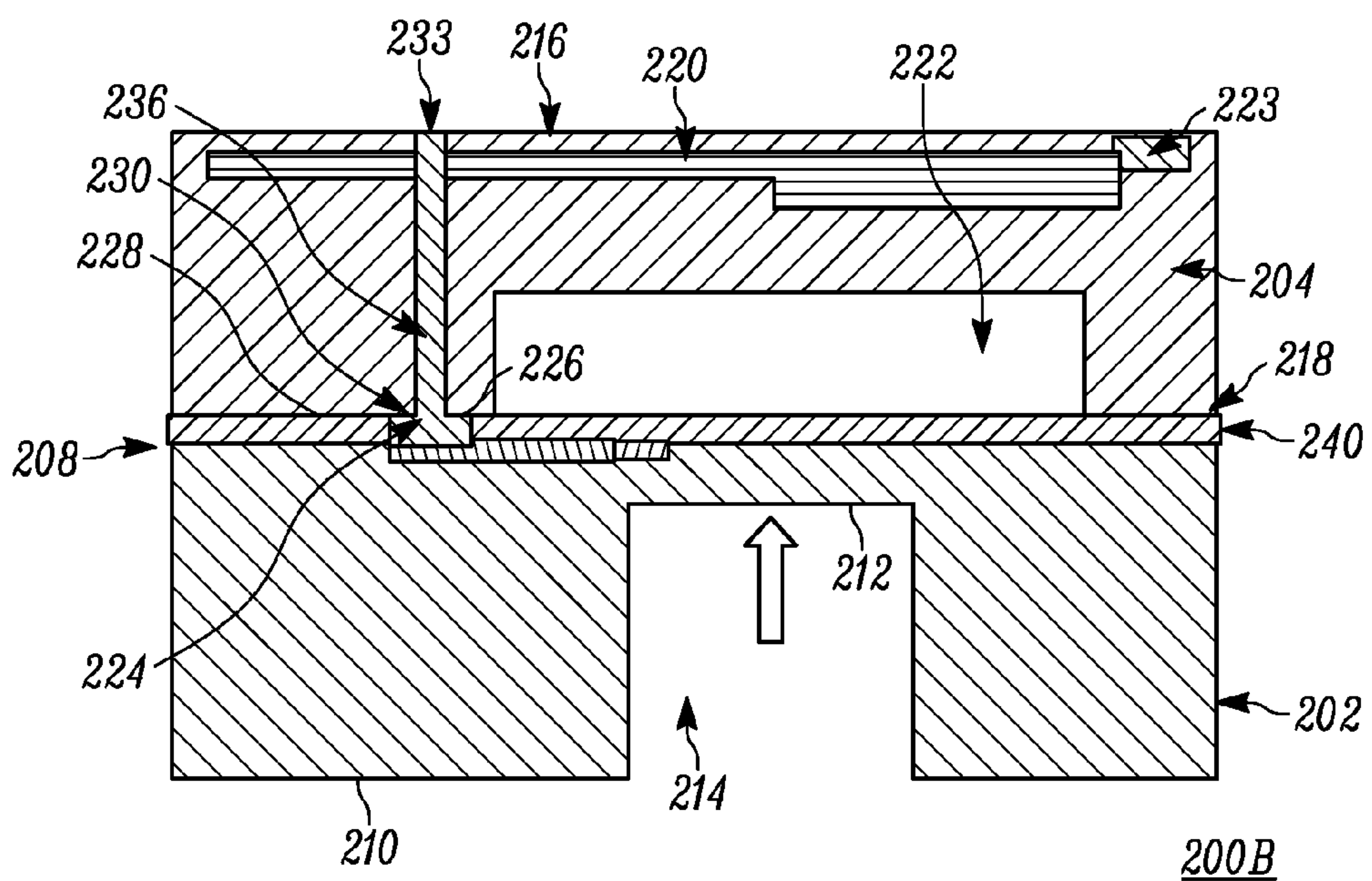


FIG. 2B

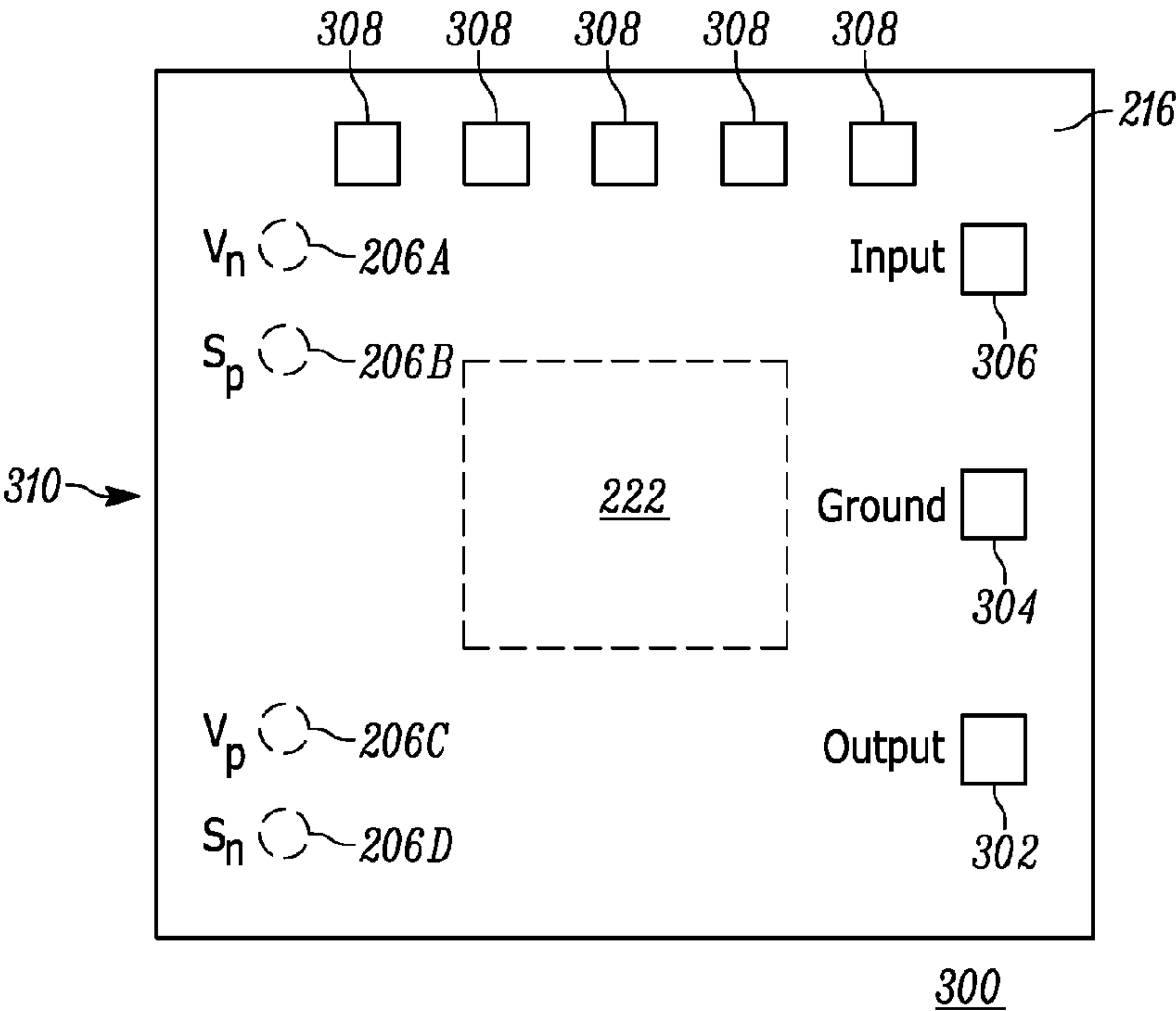


FIG. 3

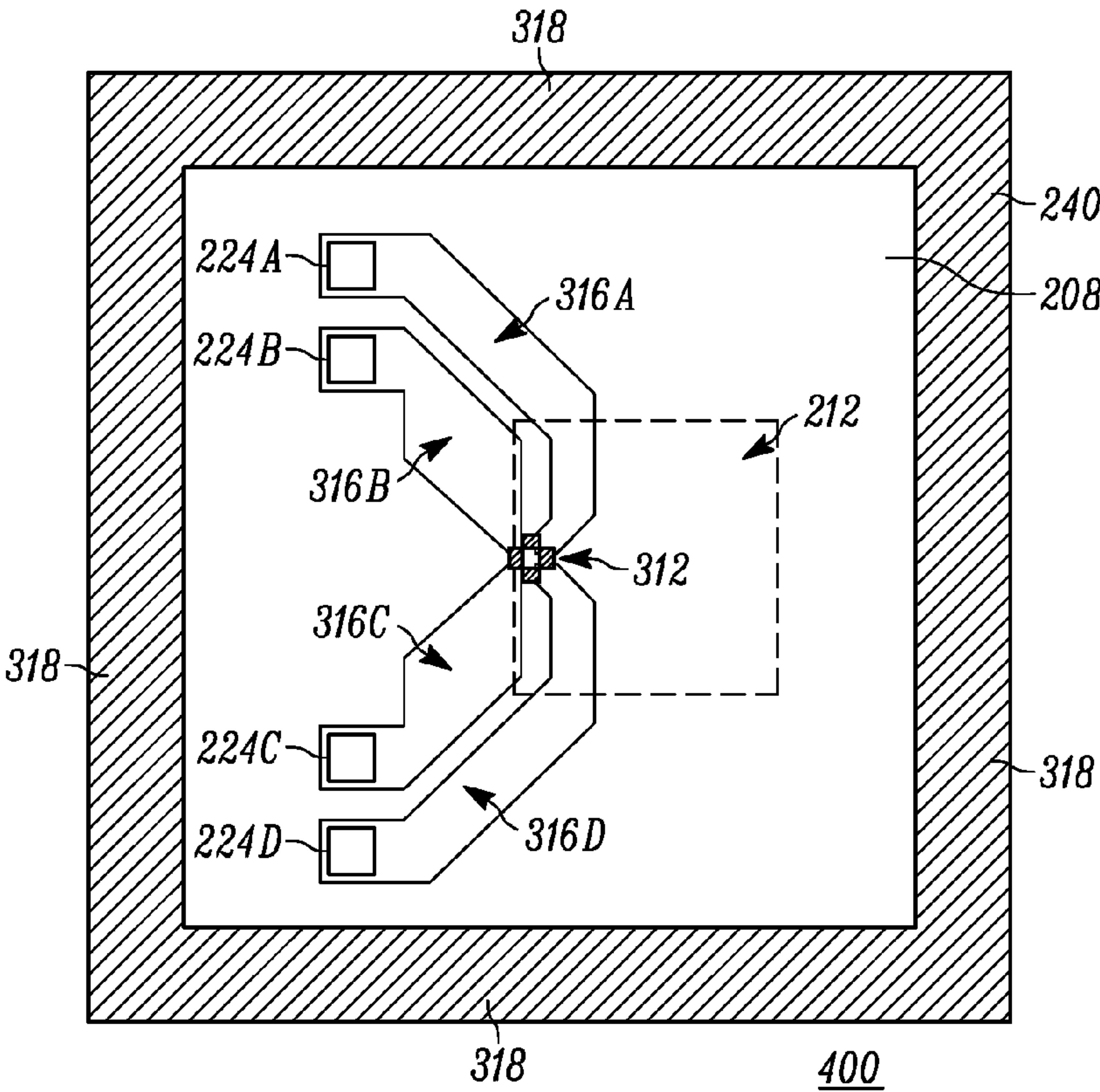


FIG. 4

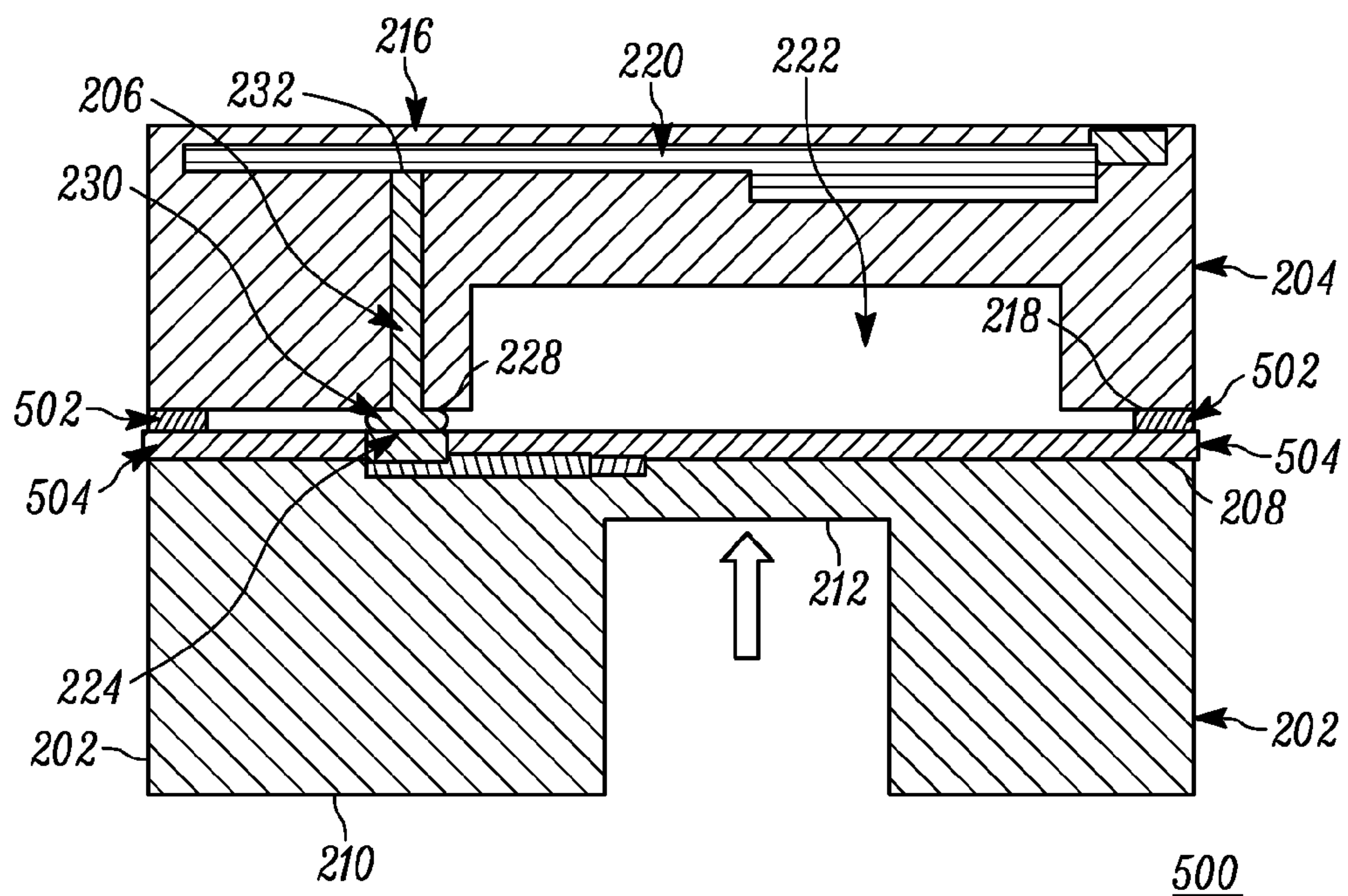


FIG. 5

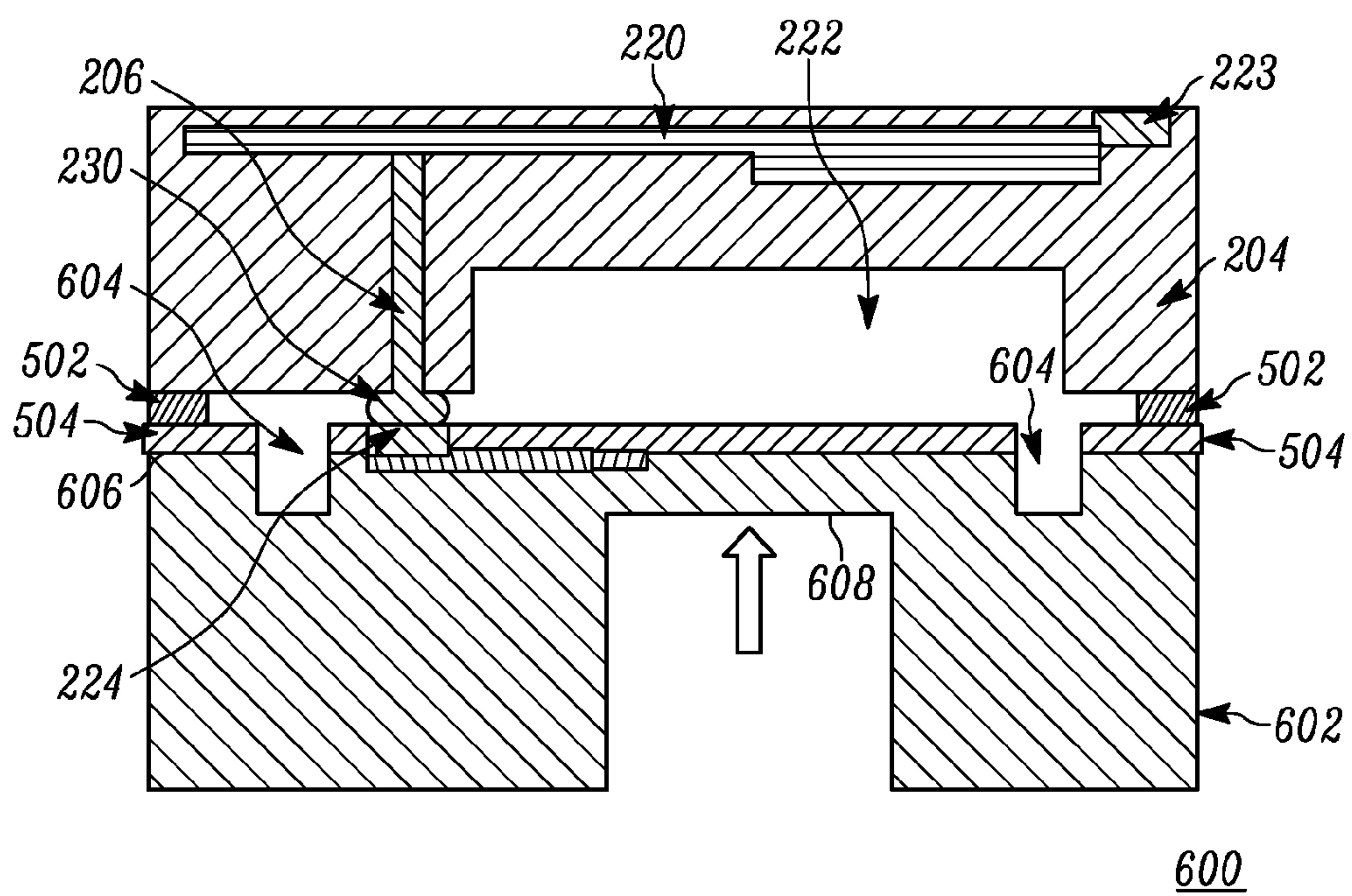


FIG. 6

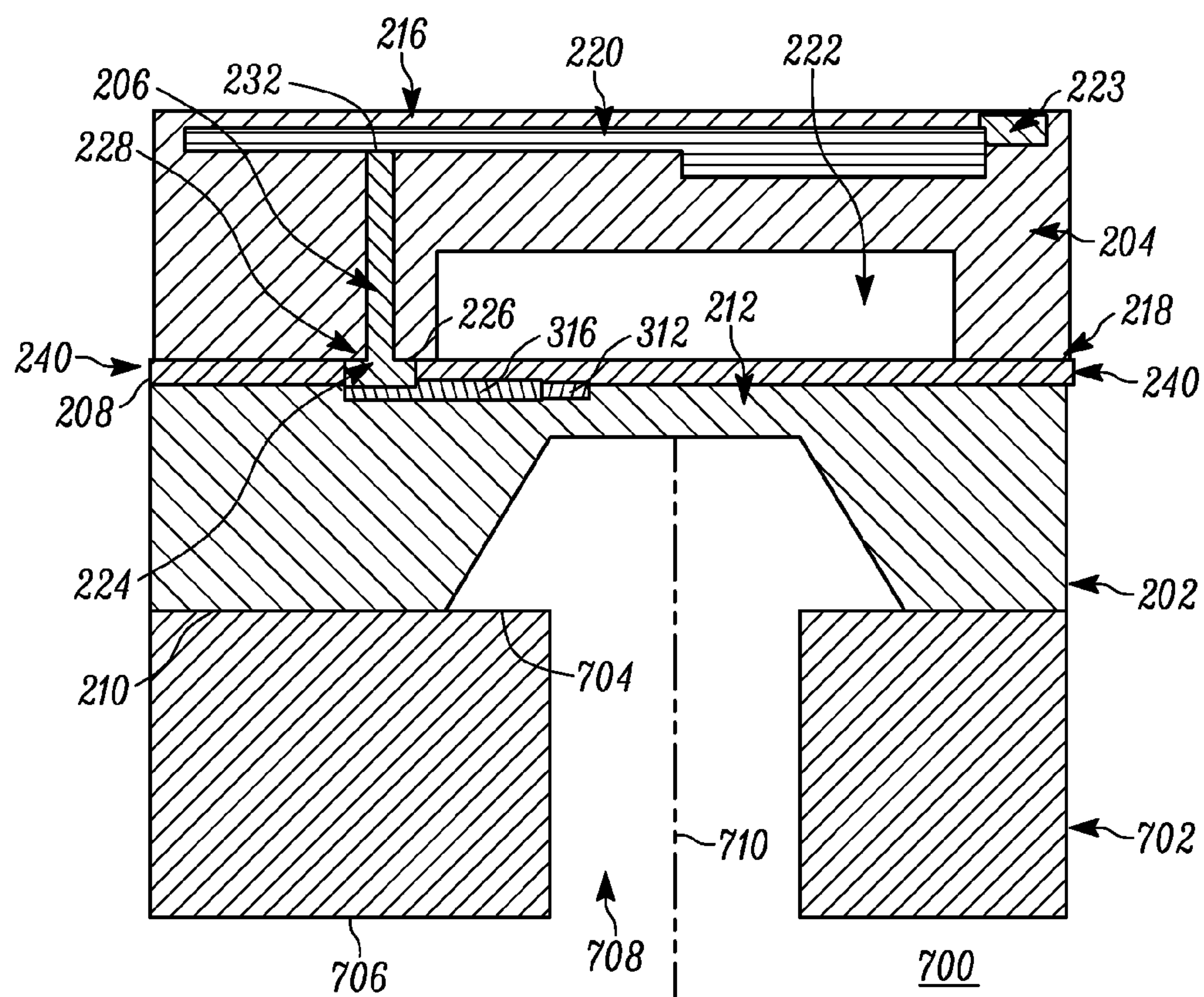


FIG. 7

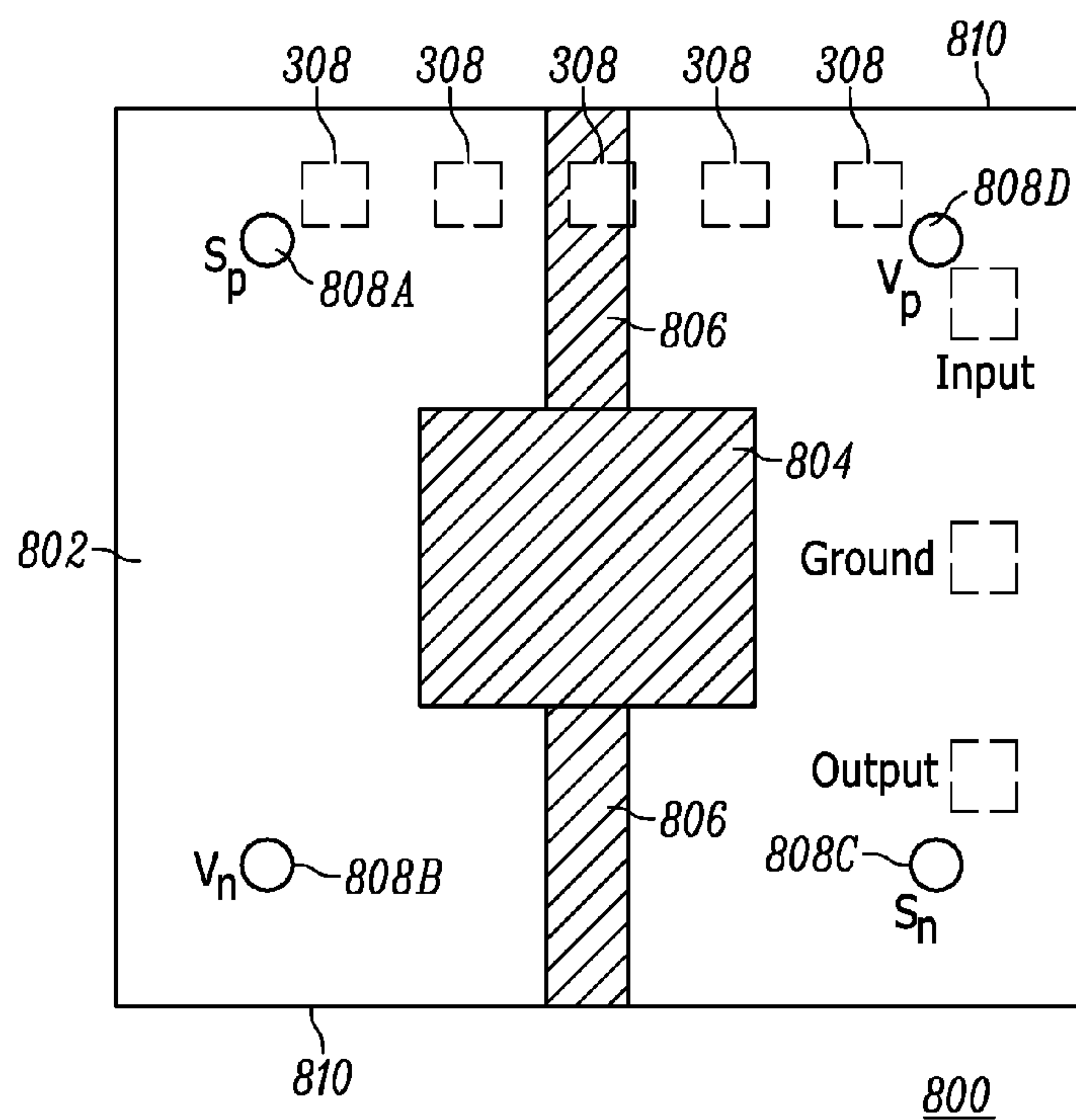


FIG. 8A

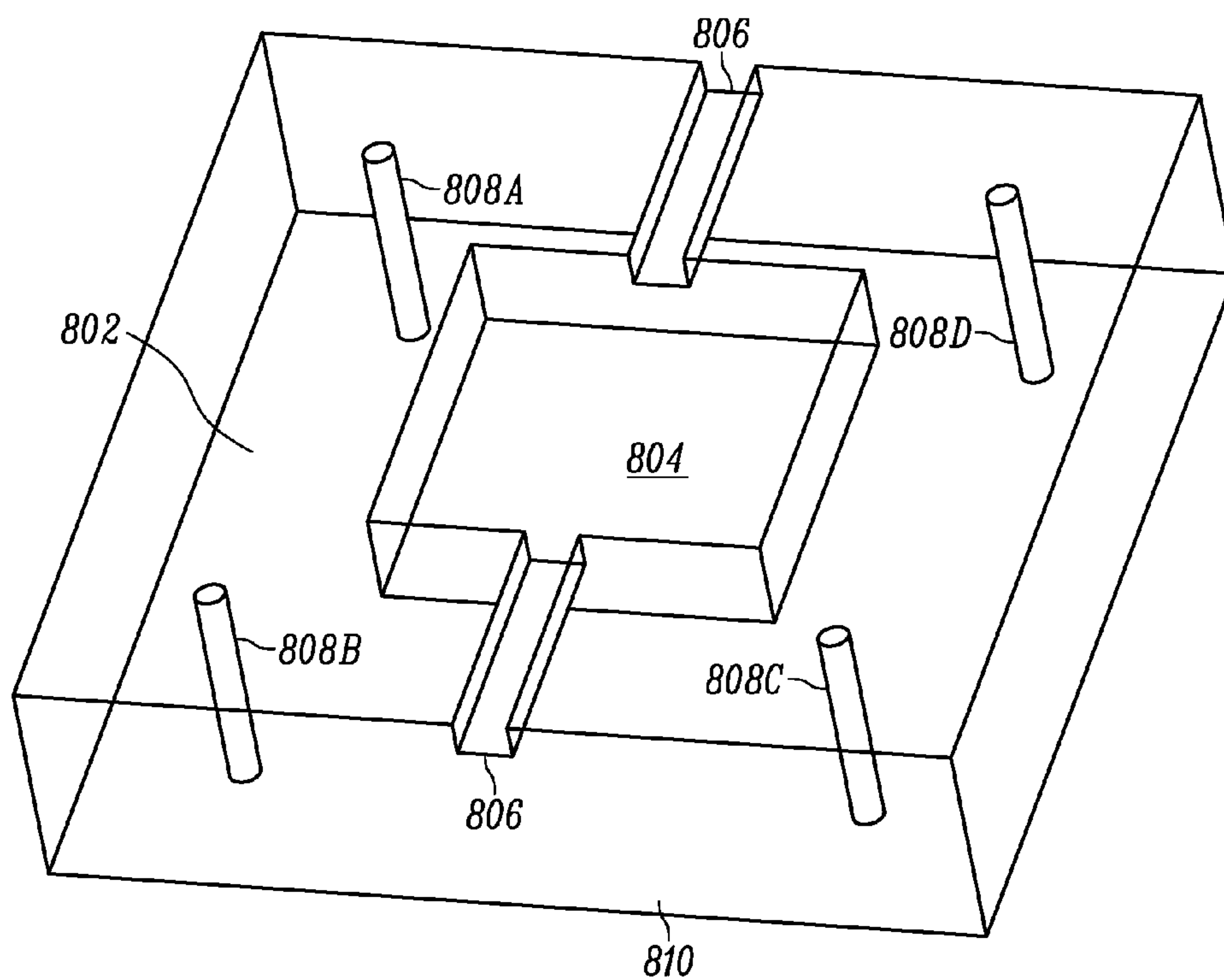


FIG. 8B

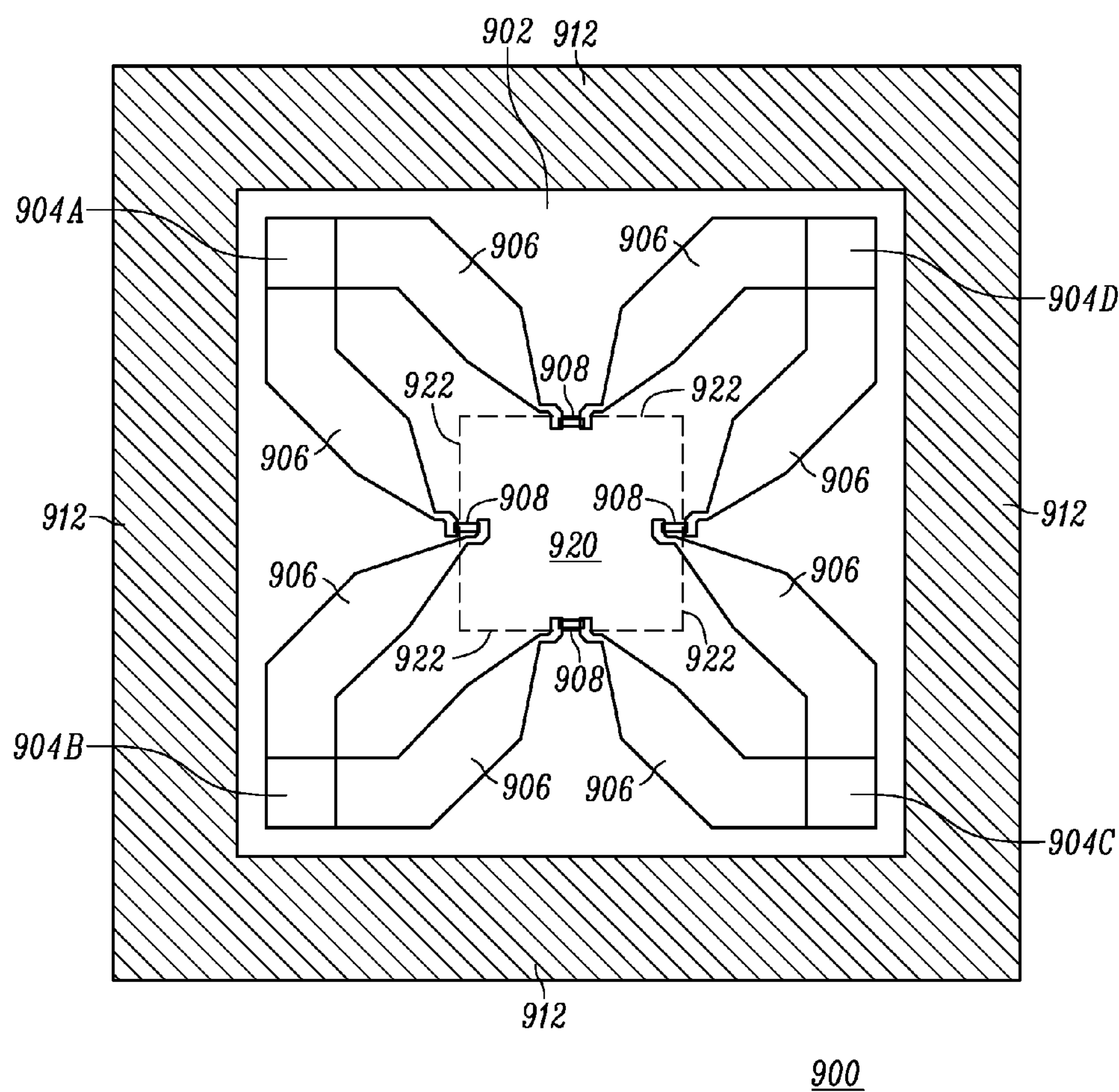


FIG. 9

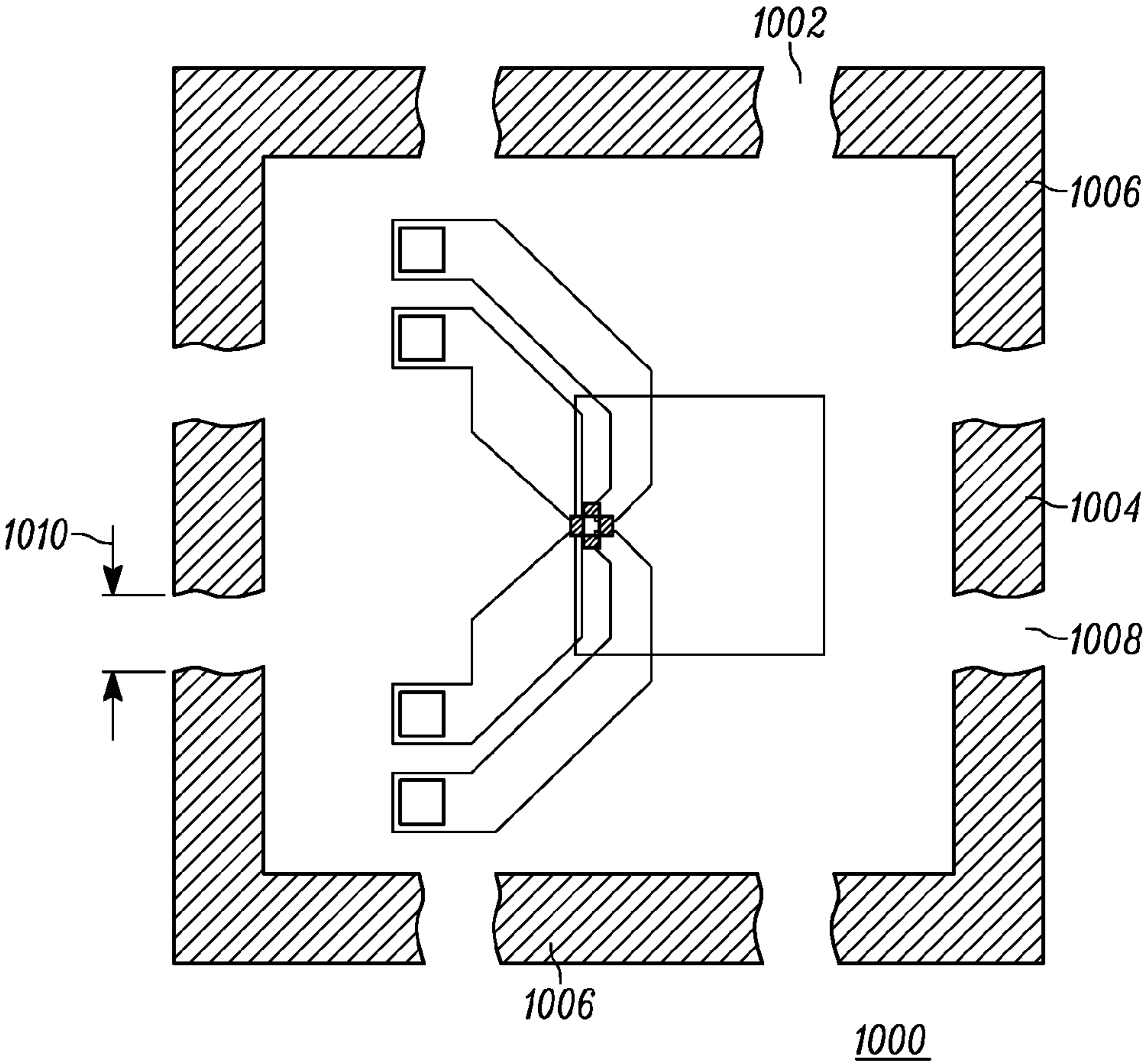


FIG. 10

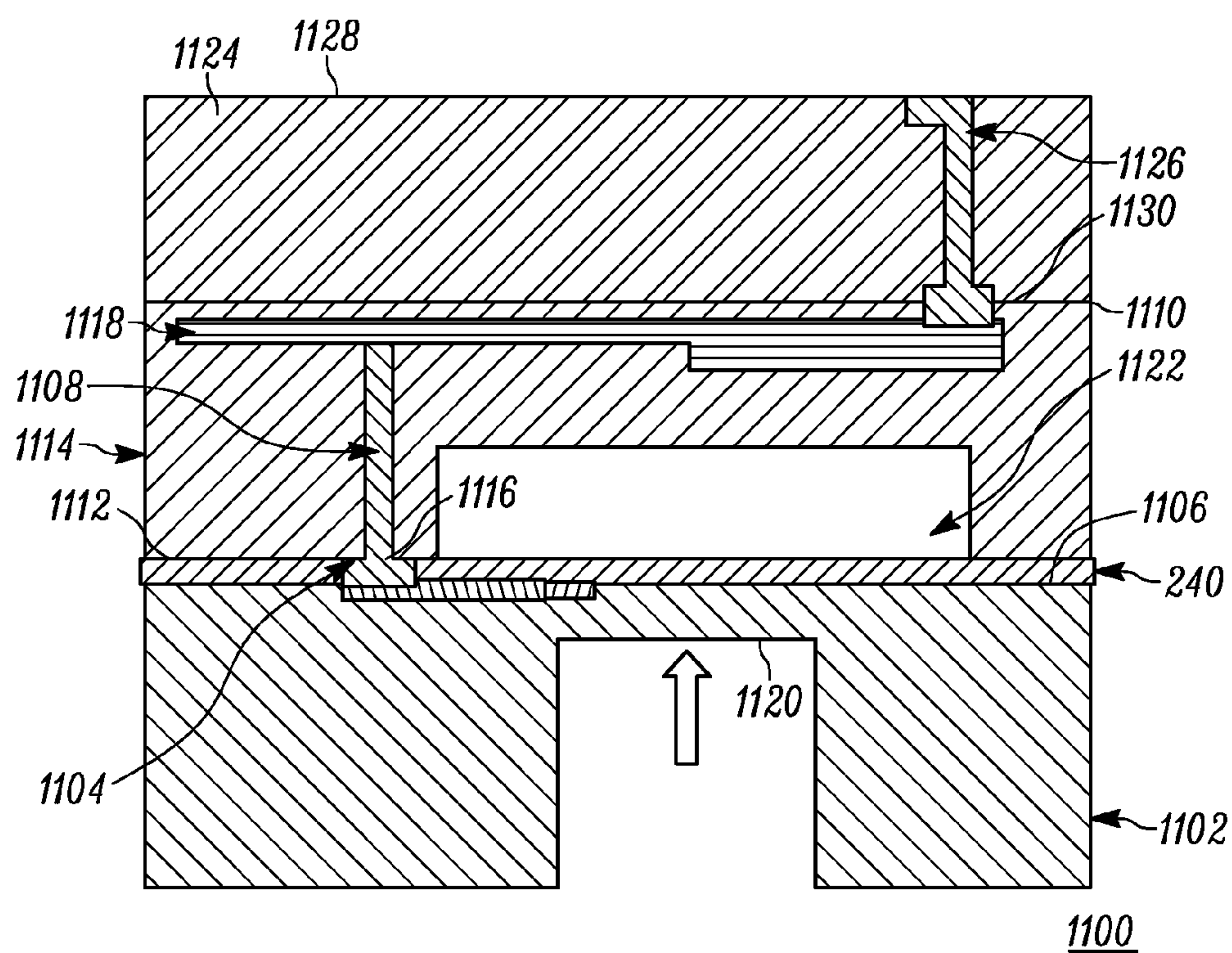


FIG. 11

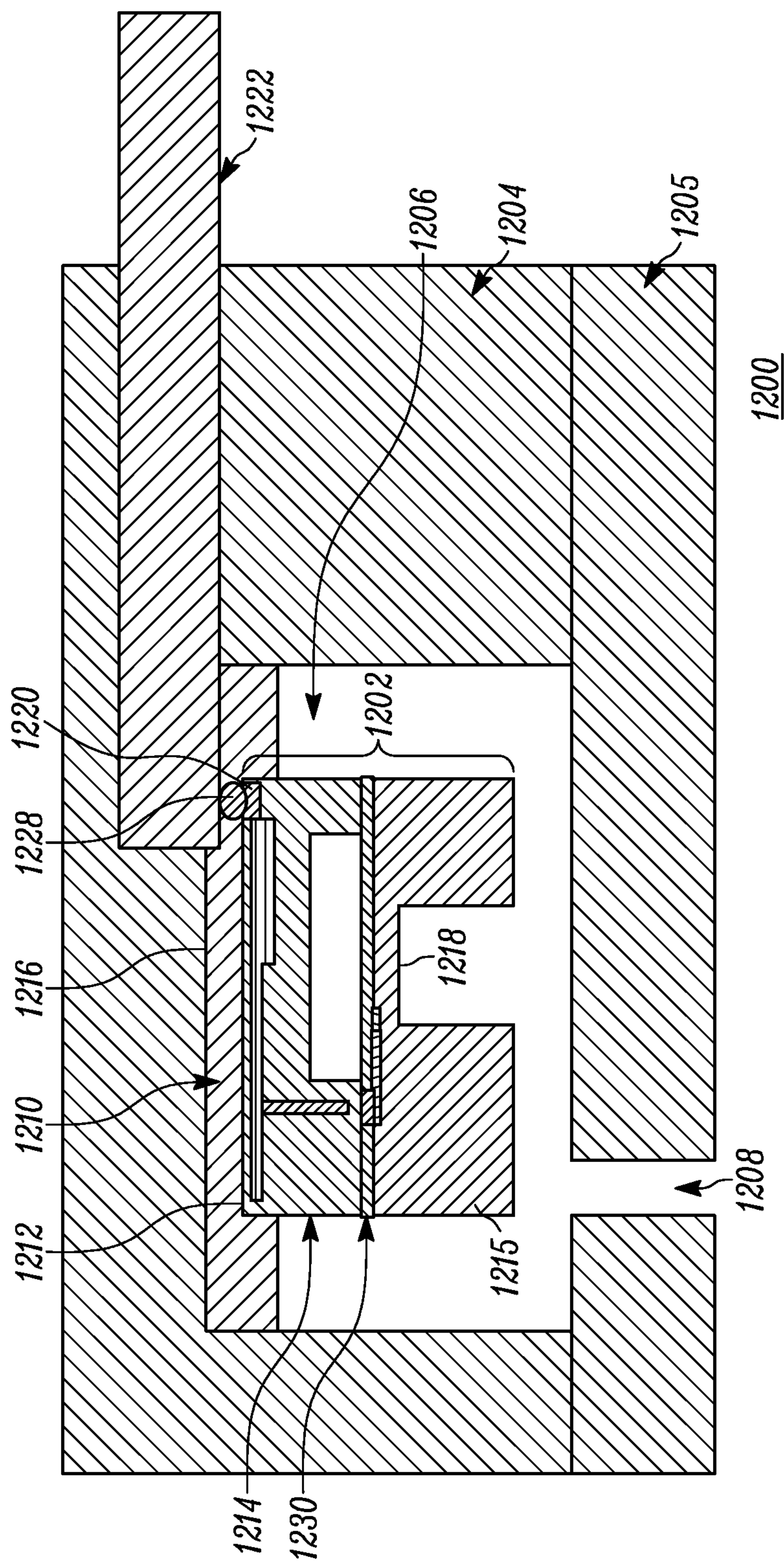


FIG. 12

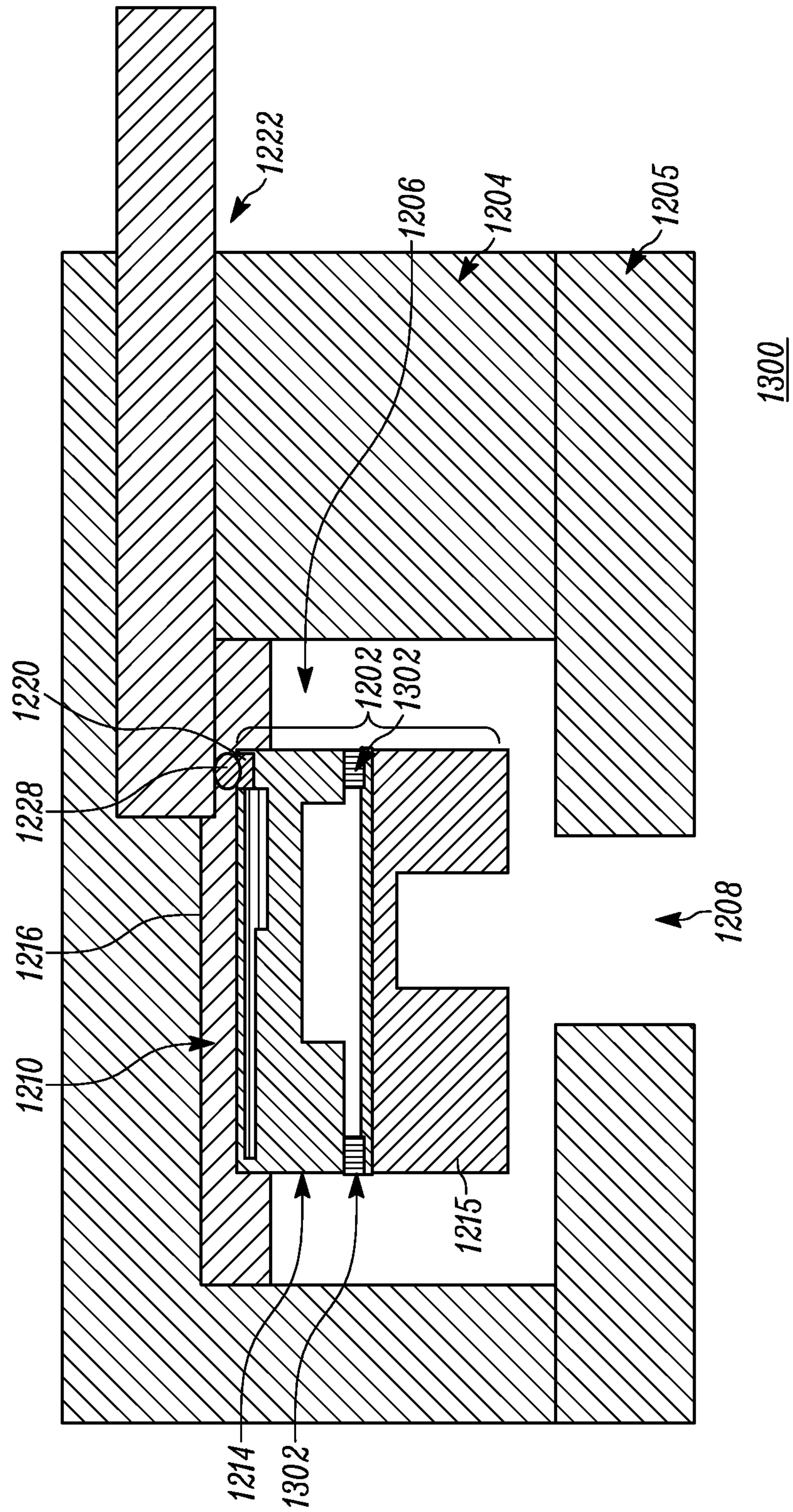


FIG. 13

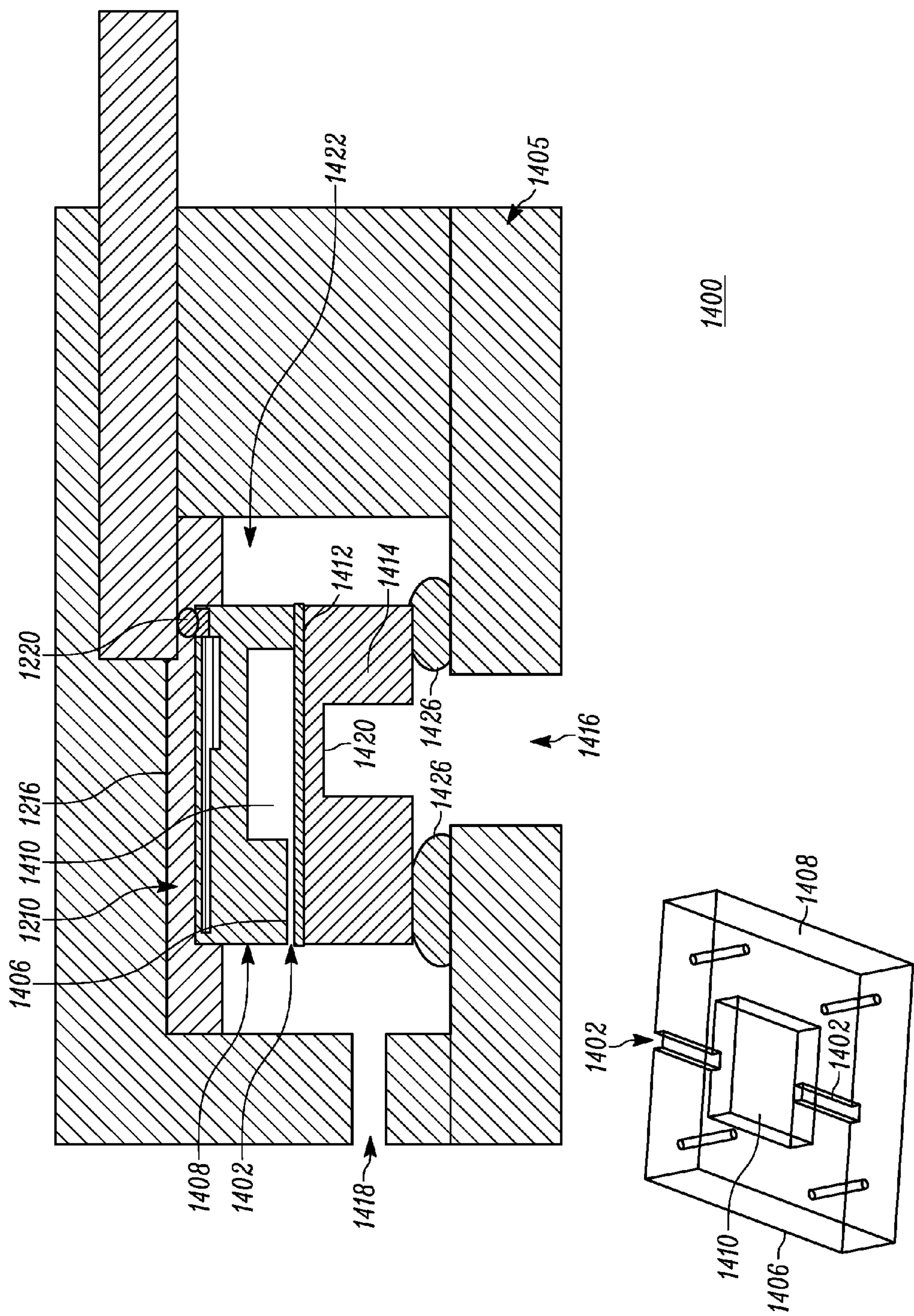


FIG. 14

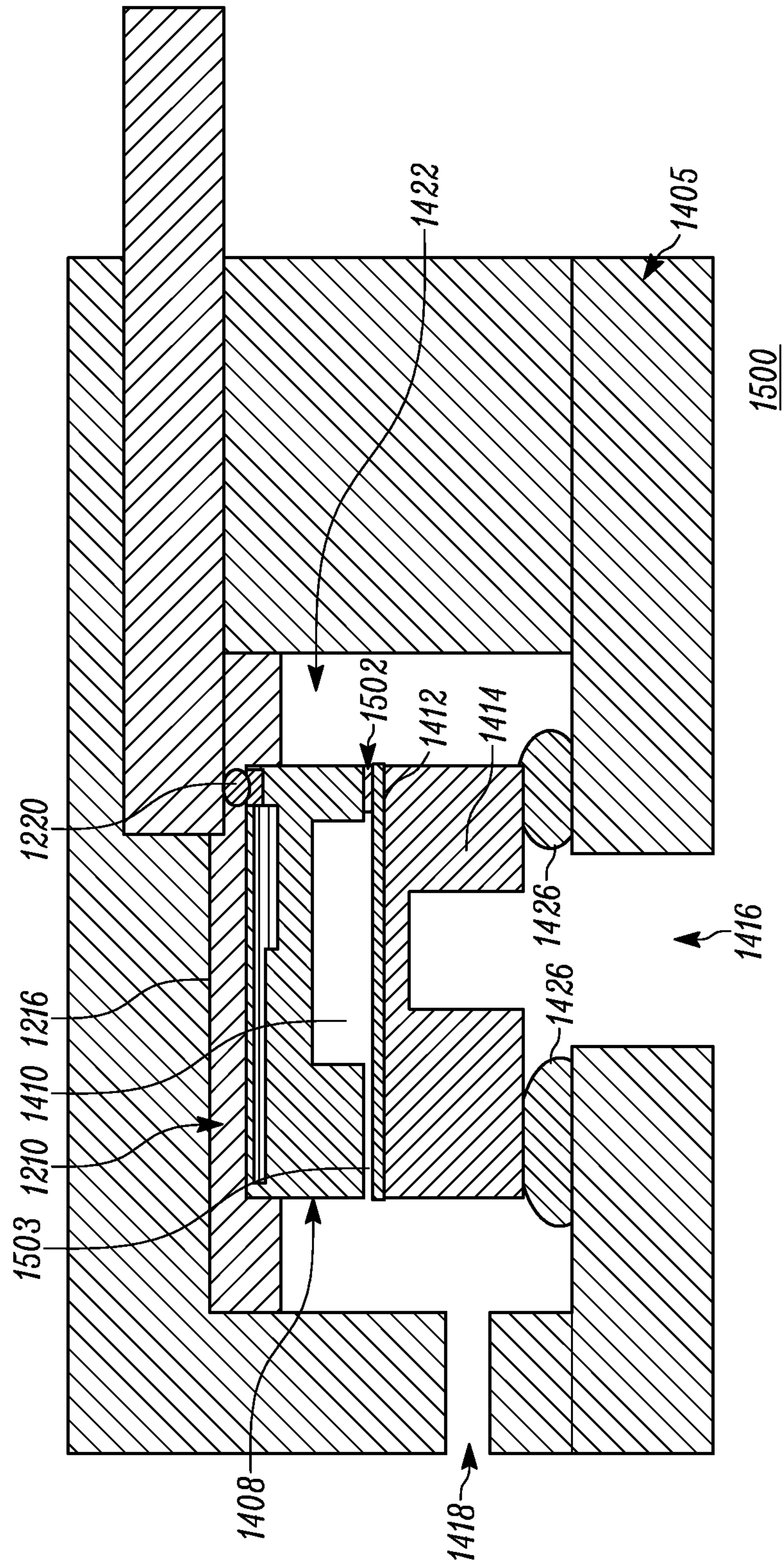


FIG. 15

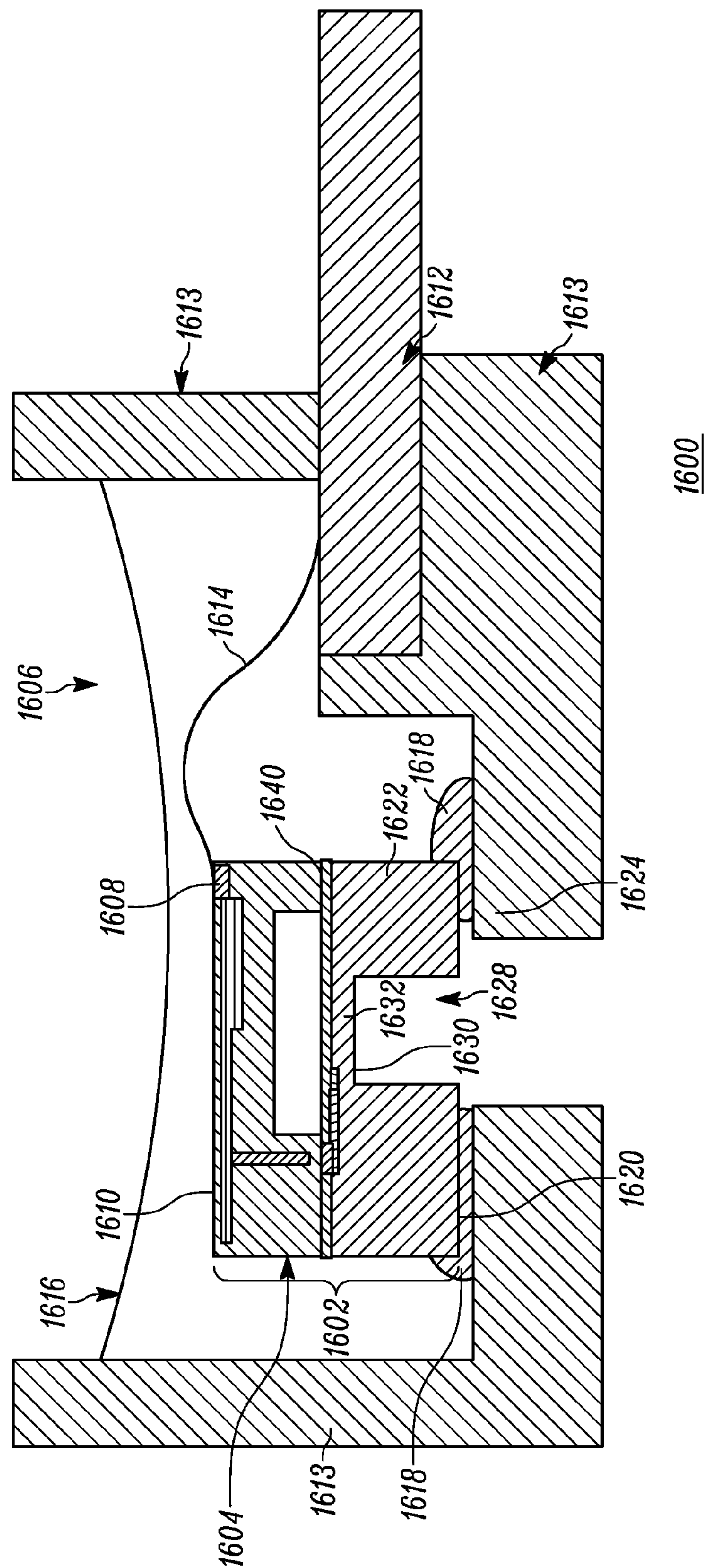


FIG. 16

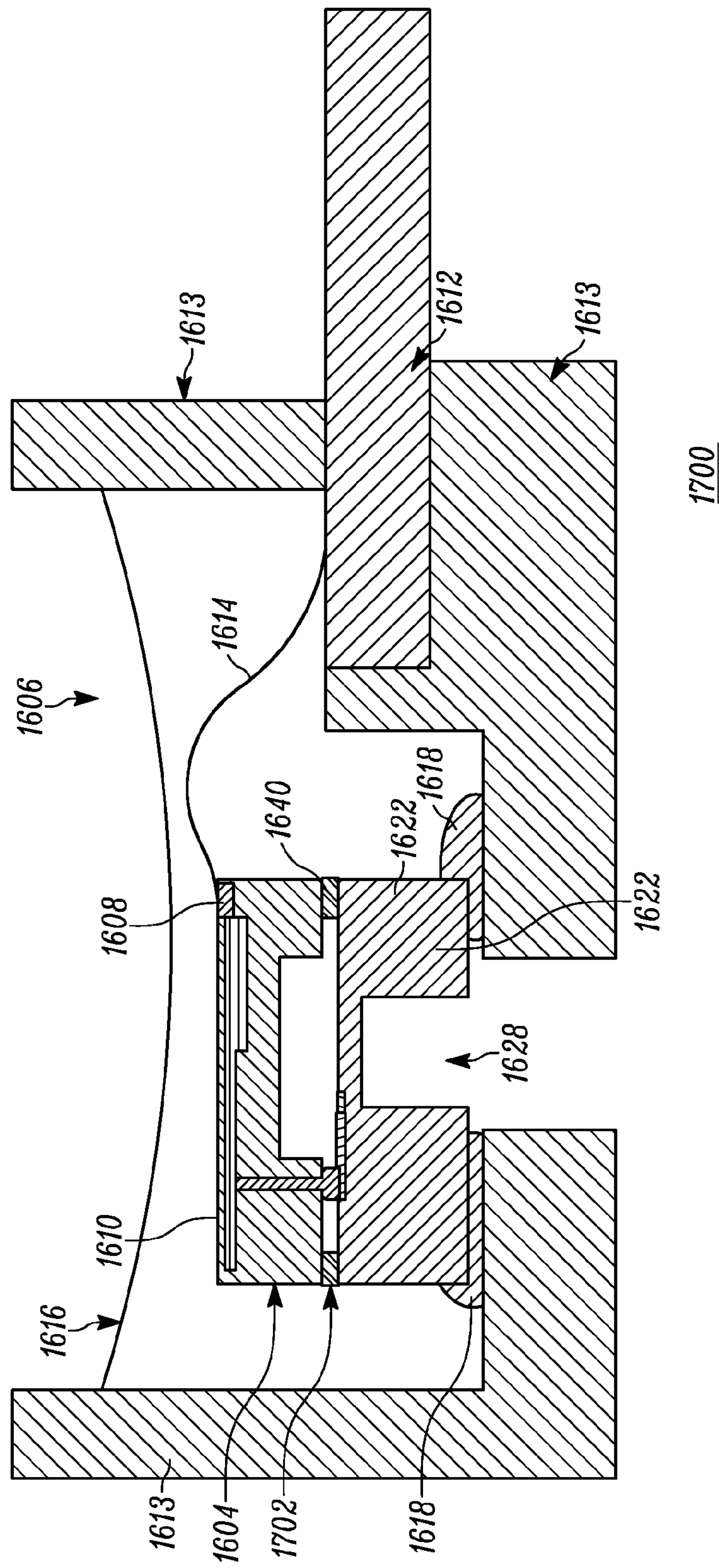


FIG. 17

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3D STACKED PIEZORESISTIVE PRESSURE
SENSOR

BACKGROUND

FIG. 1 is a cross-sectional view of a prior art MEMS piezoresistive pressure sensor module 100. It provides excellent pressure measurements for a wide range of fluids across a wide range of low pressures.

The pressure sensor module comprises essentially two dies, one is a MEMS pressure sensing element 104 and the other is an application specific integrated circuit (ASIC) identified by reference numeral 106. A vacuum cavity 103 is formed between a diaphragm 105 and a substrate 107 in the pressure sensing element 104. When pressure is applied on the diaphragm 105, the diaphragm 105 deflects and creates stresses on a Wheatstone bridge (not shown) on the diaphragm and converts the diaphragm deflection into a measurable voltage change. The two dies 104 and 106 are mounted to a housing substrate 112 using an adhesive 114. Small-diameter bond wires 102 extend and connect between the MEMS pressure sensing element 104 and the ASIC 106. The bond wires 102 also extend and connect between the ASIC 106 and a lead frame 110.

The wires 102 add cost and are of course susceptible to failure. Eliminating wires that extend between the MEMS pressure sensing element 104 and the ASIC 106 and between the ASIC 106 and the lead frame 110 would reduce cost and improve the reliability of the MEMS pressure sensing element and MEMS pressure sensors.

A viscous gel 116 inside a pocket 101 protects the pressure sensing element 104, the ASIC 106, and the bond wires 102 from pressurized media, the pressure of which is to be measured. The gel 116 needs to be soft enough in order to transmit pressure. The gel 116 on the top of the diaphragm 105, however, can cause a power-on voltage shift of the signals output from the device if high charges are stored in the gel. The gel 116 can also affect sensing accuracy in a severe vibration environment because of its mass. The gel 116 is expensive especially in a large pocket with two separated dies or chips 104 and 106. Reducing the pocket size, eliminating the gel and bond wires, or at least reducing gel quantity, or replacing expensive gel by less expensive gel for lower cost and better performance, would be an improvement over the prior art.

SUMMARY OF THE INVENTION

The protective gel and bond wires can be eliminated and the size of a pocket holding a pressure sensor device can be significantly reduced by stacking an application specific integrated circuit (ASIC) with a cavity on top of a MEMS pressure sensing element. The ASIC and pressure sensing element are electrically connected to each other using conductive vias formed into the ASIC.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 depicts a prior art topside absolute pressure sensing element inside a pocket, which is connected to an application specific integrated circuit (ASIC) by bond wires;

FIG. 2A is a cross-sectional view of a first embodiment of a backside pressure sensor device comprising a MEMS pressure sensing element and an ASIC, which are coupled to each other with conductive vias that extend through the backside of the ASIC;

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FIG. 2B is a cross-sectional view of a second embodiment of a backside pressure sensor device comprising a MEMS pressure sensing element and an ASIC, which are coupled to each other with conductive vias that extend completely through the backside of ASIC with circuitry formed in the top side of the ASIC;

FIG. 3 depicts a first or top side of the ASIC depicted in FIGS. 2A and 2B and shows in broken lines, the relative locations of conductive vias that extend through the backside of ASIC and metal bond pads on the top side;

FIG. 4 depicts the first or top side of the MEMS pressure sensing element and metal bond pads or terminals, which are aligned with and mate with the vias in FIG. 3;

FIG. 5 is a cross-sectional view of a third embodiment of a pressure sensor device comprising a MEMS pressure sensing element and an ASIC, which are coupled to each other by glass frit and solder bumps with conductive vias that extend through the backside of the ASIC;

FIG. 6 is a cross-sectional view of a fourth embodiment of a pressure sensor device comprising groove on the top side of a MEMS pressure sensing element of the third embodiment shown in FIG. 5;

FIG. 7 is a cross-sectional view of the first embodiment of a pressure sensor device with a pedestal mounted onto the backside of a MEMS pressure sensing element;

FIG. 8A is a plan view of the second or bottom side of an ASIC and that depicts a recess and trenches on the second or bottom side of the ASIC, exposed ends of conductive vias that mate with corresponding bond pads on a MEMS pressure sensing element;

FIG. 8B is a perspective view of the second or bottom side of ASIC depicted in FIG. 8A;

FIG. 9 depicts the first or top side of a MEMS pressure sensing element with metal bond pads that mate with the vias shown in FIG. 8A and depicting a bonding area either by fusion or glass frit bond around the perimeter of the first or top side;

FIG. 10 depicts the first or top side of a MEMS pressure sensing element with metal bond pads that mate with the vias shown in FIG. 8A and a patterned layer of glass frit, the glass frit pattern providing openings through which a monitored fluid can pass;

FIG. 11 depicts an alternate embodiment of a pressure sensor device having two integrated circuits stacked on top of a MEMS pressure sensing element;

FIG. 12 depicts a first embodiment of a backside absolute pressure sensor module comprising a backside absolute pressure sensor device as shown in at least FIG. 2A, a housing in which the pressure sensor device is located and a lead frame, which extends through the housing and having a fusion bond between the ASIC and the MEMS pressure sensing element;

FIG. 13 depicts a second embodiment of a backside absolute pressure sensor module, which has a glass frit bond between the ASIC and the MEMS pressure sensing element;

FIG. 14 depicts a cross section of a differential pressure sensor module having a fusion bond between the ASIC and the MEMS pressure sensing element;

FIG. 15 depicts a cross section of a second embodiment of a pressure sensor module having a patterned glass frit bond between the ASIC and MEMS pressure sensing element;

FIG. 16 depicts a cross section of a pressure sensor module comprising a backside absolute pressure sensor device formed by fusion bond, such as the one shown in at least FIGS. 2A and 2B, the ASIC metallic bond pads of

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which are connected to lead frames using bond wires that are protected by a viscous gel; and

FIG. 17 is a cross section of an alternate embodiment of a backside absolute pressure sensor module as shown in FIG. 16, formed by a patterned glass frit bond.

DETAILED DESCRIPTION

The I.E.E.E. Standards Dictionary, Copyright 2009 by the IEEE, defines “via” as a physical connection between two different levels of interconnect, or between a level of interconnect and a physical or logical pin. As used herein, a via is a vertical or substantially vertical column of conductive material formed into a substrate having opposing top and bottom or first and second sides. A via can extend all the way through a substrate, i.e., between and through opposing top and bottom/first and second sides but as shown in the accompany figures it can also extend only part way through a substrate. A via provides a vertically-oriented conductive pathway through or part way through a semiconductor substrate.

As used herein, the term “bond pad” refers to the conductive areas commonly found on an ASIC or a MEMS pressure sensing element of the prior art. The term should not, however, be construed as limited to conductive areas used in the prior art but should instead be more broadly construed to include any size conductive area on a surface of either an ASIC or a MEMS pressure sensing element, to which an electrical connection can be made.

Thin bond wires, which in prior art pressure sensor devices extend between bond pads on an ASIC and bond pads on a MEMS pressure sensing element are eliminated by vertically stacking the ASIC on top of a MEMS pressure sensing element. The two devices are connected electrically using vias formed into the ASIC and located to align with bond pads on the MEMS pressure sensing element. The vias are positioned or located in ASIC substrate so that when the ASIC is placed on a MEMS pressure sensing element, the vias align with bond pads on the MEMS pressure sensing element to which prior art bond wires would be attached.

FIG. 2A is a cross-sectional view of a first embodiment of a backside absolute pressure sensor device 200 comprising a microelectromechanical system (MEMS) pressure sensing element 202 on top of which is an application specific integrated circuit (ASIC) 204. The MEMS pressure sensing element 202 is similar to the MEMS pressure sensing element described in U.S. Pat. No. 8,215,176 and U.S. Pat. No. 8,466,523. Both prior art patents also disclose an ASIC, which both patents describe as being connected to a MEMS pressure sensing element using bond wires. Both patents are incorporated herein by reference in their entirety.

The MEMS pressure sensing element 202 has a top side 208 and an opposing bottom side 210. The top side 208 includes a flexible diaphragm 212. The diaphragm 212 deflects upwardly and downwardly responsive to pressure and/or vacuum applied to the diaphragm 212 through a pressure port 214 formed into the bottom 210 of the element 202.

As shown in FIG. 4, a Wheatstone bridge circuit is formed on the topside 208 of the MEMS pressure sensing element 202 by four P-doped piezoresistors 312 near an edge 314 of the diaphragm 212 and four interconnects 316A-316D. The four piezoresistors 312 are electrically connected to the metal bond pads 224A-224D by the four interconnects 316A-316D, which are P+ doped localized regions of the top side 208. The Wheatstone bridge circuit shown in FIG. 4, is

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called a picture-frame Wheatstone bridge (PFWB) or a localized Wheatstone bridge (LWB).

A different type of Wheatstone bridge circuit is depicted in FIG. 9 with each piezoresistor 908 doped and located near each associated diaphragm edge 922 on the top side of a diaphragm 920. This type of Wheatstone bridge circuit is called a distributed Wheatstone bridge (DWB).

As with the MEMS pressure sensing element, the ASIC 204 has a top side 216 and an opposing bottom side 218. Passive and active electronic devices that comprise a circuit 220 are formed into the top side 216 by conventional integrated processing techniques well known to those of ordinary skill in the integrated circuit art.

Unlike the ASICs used in prior art, the ASIC 204 shown in FIG. 2A has a bottom or second side 218, which is formed to have a recess 222, which is a hollowed-out space formed into the bottom or second side 218. When the ASIC 204 having a recess 222 is attached to a MEMS pressure sensing element 202 in a vacuum or near vacuum, the recess 222 becomes or defines an evacuated cavity 222 that is directly above the diaphragm 212. Being evacuated, the cavity 222 does not exert force on the diaphragm 212 facilitating its deflection responsive to pressure of a fluid in a pressure cavity 214.

As shown in FIG. 2A, the metal bond pads 224 of the MEMS pressure sensing element 202 are located directly below conductive vias 206 that extend from the bottom side 218 of the ASIC 204 to electronic circuitry formed in the top side 216 of the ASIC. An electrical connection between the bond pads 224 on the top surface 208 of the MEMS pressure sensing element 202 and the bottom end 228 of a conductive via 206 is assured by an intermetallic bond pad 230 that is attached to the bottom end 228 of a conductive via 206 on the bottom or second side of the ASIC 204. The top end 232 of the conductive via 206 is connected to the electrical circuitry 220 by conventional circuit traces formed in the circuitry 220 itself. The vias 206 thus provide a solid electrical pathway between the Wheatstone bridge circuit of the MEMS pressure sensing element 202 and electrical circuitry 220 formed into the top or first side 216 of the ASIC 204.

The MEMS pressure sensing element 202 is attached to the ASIC 204 by a bonding layer of silicon dioxide 240. Input and output signals of the ASIC 204 are available at metal bond pads 223 located on the top side 216 of the ASIC 204.

FIG. 2B is a cross-sectional view of a second embodiment of a backside absolute pressure sensor device 200 comprising a MEMS pressure sensing element 202 on top of which is an application specific integrated circuit (ASIC) 204. The embodiment of FIG. 2B differs from the one shown in FIG. 2A by conductive vias 206B that extend completely through the topside 216 of the ASIC 204.

As FIG. 2B shows, the top end 233 of the via 236 is exposed for an electrical connection. Such a via 236 can connect to circuitry 220 formed in the top side of the ASIC 204 and continue to extend upwardly from the circuitry 220 to the top side 216 of the ASIC 204.

FIG. 3 is a plan view of the first or top side 216 of the ASIC 204 shown in FIG. 2A. FIG. 3 thus shows in phantom lines four conductive vias 206A-206D, each of which extend part way up the ASIC 204 from its backside 218, not visible in FIG. 3, toward the topside 216 of the ASIC 204. The vias 206A-206D are located or positioned in the ASIC to be directly above where metal bond pads 224A-224D are located on the top surface of a MEMS pressure sensing element 202 as shown in FIG. 4 so that the vias 206A-206D

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align with the bond pads **224** when the ASIC **204** is placed on top of the MEMS pressure sensing element **202**.

As shown in FIG. 3, the vias **206A-206D** are located along one side **310** of the ASIC **204** but can also be symmetrically distributed around the recess **222** formed into the opposing bottom side **218** of the ASIC **204**, as shown in FIGS. 8A and 8B. The location of the recess **222** is depicted in FIG. 3A as a square drawn in broken or phantom lines. Symmetric distribution of the vias around the recess **222** reduces stress concentrations in the ASIC **204**.

The top side **216** of the ASIC **204** is provided with several metal bond pads **302**, **304**, **306** and **308**. Three of the bond pads **302**, **304** and **306** are denominated as output, ground and input respectively. Five other bond pads **308** are for testing the ASIC **204**.

FIG. 4 depicts the first or top side **208** of the MEMS pressure sensing element **202**. FIG. 4 also depicts the location of four metal bond pads **224A-224D** on the top side **208** of the MEMS pressure sensing element **202**.

A Wheatstone bridge circuit is formed by four P- doped piezoresistors **312** near an edge **314** of the diaphragm **212** and four interconnects **316A-316D**. The four piezoresistors **312** are electrically connected to the metal bond pads **224A-224D** by the four interconnects **316A-316D**, which are P+ doped localized regions of the top side **208**.

In the first embodiment of the pressure sensor device **200**, the top side **208** of the MEMS pressure sensing element **202** is attached to the bottom side **218** of the ASIC **204** by a fusion bond. In one embodiment, except for the metal bond pads, the entire top side **208** of the MEMS pressure sensing element **204** is covered with a silicon dioxide layer, which is used to form a silicon fusion bond. In FIG. 4, a fusion bonding area **318** is provided with a thin layer of silicon dioxide, which when heated provides a silicon fusion bond between the MEMS pressure sensing element **202** and the ASIC **204**. The silicon dioxide **240** in the fusion bonding area **318** can form a silicon fusion bond. In yet another embodiment, also shown by FIG. 4, the silicon dioxide **240** in the fusion bonding area **318** is additional silicon dioxide placed on top of a layer of silicon dioxide that extends over the entire top surface **208** of the MEMS pressure sensing element **204**. In all three embodiments, an intermetallic bond **230** is formed and located between the conductive vias **206** and metal bond pads **224** as shown in FIG. 2A or an intermetallic bond **230** is formed and located between the conductive vias **236** and metal bond pads **224** as shown in FIG. 2B.

In yet other alternate embodiments, the silicon dioxide **240** can be replaced by, or substituted with a layer of glass frit, which when heated bonds the MEMS pressure sensing element **202** to the ASIC **204**. In such embodiments, i.e., where the glass frit covers the top surface **208** or is localized into the fusion bonding area **318**, a small droplet of solder referred to herein as a solder bump is used between the vias **206** and the metal bond pads **224**. The layer of silicon dioxide **240** can also be placed onto the backside of the ASIC **204**.

In yet another embodiment, the cavity/recess above the MEMS pressure sensing element is not evacuated but is instead provided with a fluid having a pressure that is to be sensed, or which is to affect the measurement of a fluid pressure applied to the diaphragm, as required by a differential pressure sensor. In order to apply a fluid pressure into the cavity, a pathway into the cavity must of course be provided.

In order to provide a fluid pathway into the cavity **222**, the layer of either silicon dioxide or glass frit (or a mixture of

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them) between the ASIC **204** and the MEMS pressure sensing element **202** can be patterned, as shown in FIG. 10, which shows the top side **1002** of a MEMS pressure sensing element **1000** having a patterned bonding area **1004**. Strips or regions **1006** of either silicon dioxide or glass frit or a mixture of them are separated from each other by spaces **1008** where no silicon dioxides or glass frit is applied to the top side **1002** of the MEMS pressure sensing element **1000**. The open spaces **1008** have a predetermined width **1010** and a height, which extends out of the plane of FIG. 10 by a distance substantially equal to the thickness of the silicon dioxide or glass frit. For air, the thickness of the bonding layer is preferably at least 20 microns up to about 200 microns. The open spaces **1008** are thus sized, shaped and arranged to allow a particular fluid to pass through them and into the recess **222** formed into the second side of the ASIC **204**.

FIG. 5 is a cross-sectional view of a third embodiment of a backside absolute pressure sensor device **500** comprising the MEMS pressure sensing element **202** and the ASIC **204** having conductive vias **206** that extend up from the bottom side **218** of the ASIC **204** part way through the ASIC **204**. The embodiment of FIG. 5 differs from the embodiment shown in FIG. 2-4 by how the ASIC **204** and sensing element **202** are attached to each other.

In the embodiment shown in FIG. 5, the MEMS pressure sensing element **202** and the ASIC **204** are bonded to each other using a layer of glass frit **502** on the bottom side **218** of the ASIC **204** and a layer of silicon dioxide **504** on the top side **208** of the MEMS pressure sensing element **202**.

FIG. 6 shows another embodiment of a pressure sensor device **600**. The ASIC **204** is attached to the top side of a MEMS pressure sensing element **602**, which has a groove **604** formed into the top side **606** of the element **602**. The groove **604**, which is shown in cross section, surrounds the diaphragm formed into the top side **606** of the MEMS pressure sensing element and collects excess glass frit during the heating required to liquefy the glass frit.

FIG. 7 is a cross-sectional view of the pressure sensor device **200** shown in FIG. 2A mounted to a pedestal **702**. The pedestal **702** has a top surface **704** and an opposing bottom surface **706**. It also has an aperture **708** that extends all the way through the pedestal **702**. The center **710** of the aperture **708** is aligned with, or at least substantially aligned with the middle of the diaphragm **212** formed in the MEMS pressure sensing element **202**. The pedestal **702** is preferably made of glass or silicon. It isolates the sensing element **202** from surfaces of a housing having thermal expansion coefficients markedly different from the thermal expansion coefficient of the material from which the sensing element **202** is made.

FIG. 8A is a plan view of an alternate embodiment of an ASIC **800**, the bottom side **802** of which has a recess **804**. FIG. 8B is a perspective view of the bottom side **802**. One or more trenches **806** are formed into the bottom side **802** of the ASIC **800**. The trenches are narrow and steep-sided cuts or depressions formed into the otherwise substantially planar surface of the bottom side **802** of the ASIC **800**. The trenches **806** extend laterally or sideways through the ASIC **800** from the recess **804** through one of the vertical sides **810** of the ASIC **800**. The trenches are sized and shaped to allow a fluid, the pressure of which is being sensed, to flow into and out of the recess **804** as well as the cavity formed by the recess **804** when the bottom side **802** of the ASIC **800** is attached to the top side of a MEMS pressure sensing element. The trenches **806**, or a patterned bonding layer depicted in FIG. 10, enable the pressure sensing element to

which an ASIC is bonded to provide differential pressure sensing. The trenches **806** preferably pass between conductive vias formed in the ASIC.

FIGS. **8A** and **8B**, which is a perspective view of the bottom side **802**, also show that conductive vias **806** can be symmetrically distributed around the recess **804**, instead of along one side of an ASIC, as shown in FIG. **2A**. In FIGS. **8A** and **8B**, one conductive via **808A-808D** is located near each corner of the ASIC **800**. Such vias **808A-808D** are thus considered herein to be symmetrically distributed in the ASIC **800**.

FIG. **9** is a plan view of an alternate embodiment of a MEMS pressure sensing element **900** having a distributed Wheatstone bridge circuit formed by four separated piezoresistors **908** and interconnects **906**. Its top surface **902** is provided corner-located metal bond pads **904A-904D**, i.e., bond pads located near the corners of the MEMS pressure sensing element **900**. The bond pads **904A-904D** are located to align with the symmetrically distributed conductive vias **806A-806D** of the ASIC **800** shown in FIG. **8** when the ASIC **800** shown in FIGS. **8A** and **8B** is placed on top of the MEMS pressure sensing element **900** shown in FIG. **9**.

Interconnects **906** are formed in the top surface **902** using P+ doping of semiconductor material between the symmetrically distributed bond pads **904A-904D** and piezoresistors **908** that are connected to form a Wheatstone bridge. A fusion bonding area **912**, described above with regard to FIG. **4**, surrounds the bond pads **904A-904D** and conductive interconnects **906**.

FIG. **11** depicts an alternate embodiment of a backside pressure sensor device **1100** having two integrated circuits stacked on the top of a backside MEMS pressure sensing element. One of the two integrated circuits is preferably an electromagnetic control chip or EMC chip, which reduces or filters electrical noise but which can have other active and/or passive devices.

The embodiment shown in FIG. **11** comprises a backside MEMS pressure sensing element **1102**. As with the MEMS pressure sensing elements described above, the pressure sensing element **1102** shown in FIG. **11** has metal bond pads **1104** on the top surface **1106** of the MEMS pressure sensing element **1102**.

The bond pads **1104** are electrically connected to conductive vias **1108** formed at least part way through a first ASIC **1114**. The vias **1108** extend between circuitry **1118** formed in the top surface **1110** of the ASIC **1114** and the bottom surface **1112** of the ASIC **1114**. An intermetallic bond **1116** is formed between the bond pads **1104** and the vias **1108**.

The vias **1108** connect circuitry **1118** in the top surface **1110** of the ASIC **1114** to the bond pads **1104** and hence connect the circuitry **1118** to a Wheatstone bridge circuit located in the diaphragm **1120** of the MEMS pressure sensing element **1102**.

The diaphragm **1120** is "covered" by an evacuated cavity **1122**. The cavity **1122** is formed from a recess **1122** cut into the bottom surface **1112** of the ASIC **1114** when the ASIC **1114** is attached to the top surface **1106** of the MEMS pressure sensing element **1102**.

The second integrated circuit **1124** is connected to the first integrated circuit **1114** by a second set of conductive vias **1126** formed into the second integrated circuit **1124**. The second set of vias **1126** extend between the top side or surface **1128** and bottom side or surface **1130** of the second integrated circuit **1124**. The second set of vias **1126** go all the way through the second integrated circuit **1124**. As can be

seen in FIG. **11**, the vias **1126** are electrically connected to the circuitry **1118** formed in the top side of the first integrated circuit **1114**.

FIG. **12** depicts a first embodiment of a pressure sensor module **1200**. The module **1200** is essentially a pressure sensor device **1202** described above, including at least the one shown in at least FIG. **2**, sealed inside an interior space of a housing **1204**. The pressure sensor device **1202** comprises an ASIC **1214** and a MEMS pressure sensing element **1215**. They are bonded to each other using a fusion bond **1230** described above.

The interior space where the pressure sensor device **1202** is located is referred to herein as a pocket **1206**. A pressure port **1208** is formed through the cover **1205** and leads into the pocket **1206**. The port **1208** is sized and shaped to allow a fluid to flow through the port **1208** and apply pressure to the diaphragm **1218** of the pressure sensor device **1202**.

The pressure sensor device **1202** is mounted to the top side **1216** of the pocket **1206** by an adhesive **1210**. An electrical connection between a lead frame **1222** and bond pads **1220** on the top side **1212** of the ASIC **1214** is provided by an electrically conductive adhesive (ECA) or a solder bump **1228**. The adhesive **1210** is non-conductive and protects the bond pad **1220** as well as the ECA or solder bump **1228**.

FIG. **13** depicts a second embodiment of a pressure sensor module **1300**. The pressure sensor module **1300** of FIG. **13** differs from the pressure sensing module **1200** of FIG. **12** by only the use of a glass frit bond **1302** between the ASIC **1214** and MEMS pressure sensing module **1215**. The glass frit bond is provided by a layer of glass frit between the ASIC **1214** and MEMS pressure sensing module **1215**.

FIG. **14** depicts a differential pressure sensor module **1400**. It differs from the pressure sensor modules shown in FIGS. **12** and **13** by the addition of a trench **1402** formed in the bottom side **1406** of an ASIC **1408**, which allows fluid to enter the cavity **1410** formed by a recess in the bottom side **1406** of the ASIC **1408** and attachment of the ASIC **1408** to the top side **1412** of a MEMS pressure sensing element **1414**.

Unlike the pressure sensor modules described above, the pressure sensor module **1400** shown in FIG. **14** is provided with two pressure ports **1416** and **1418**. A first pressure port **1416** provides a path by which fluid can apply pressure to the backside **1420** of the MEMS pressure sensing element **1414**. An adhesive **1426** attaches the MEMS pressure sensing element **1414** to the cover **1405** and provides a seal around the first pressure port **1416**.

The second pressure port **1418** provides a second and separate path by which a different fluid can apply pressure to the pocket **1422** and the cavity **1410** and hence the top side **1412** of the MEMS pressure sensing element **1414** via the trench **1402**. The pressure sensor module **1400** of FIG. **14** is used for differential pressure sensing while the pressure sensor modules shown in FIGS. **12** and **13** are used for backside absolute pressure sensing.

FIG. **15** depicts another embodiment of a differential pressure sensor module **1500**. It differs from the pressure sensor module **1400** of FIG. **14** by the use of a patterned glass frit **1502** between the ASIC **1408** and MEMS pressure sensing element **1414**. As shown in FIG. **10** and described above, the patterned glass frit **1502** provides a path **1503** for pressurized fluid to flow from the pocket **1422** into the cavity **1410** and exert pressure on the topside of the diaphragm.

FIG. **16** depicts a backside absolute pressure sensor module **1600** comprising a backside absolute pressure sensor device **1602** inside a housing **1613** having a pocket **1606**

that encloses the pressure sensor device 1602. As with the pressure sensor devices described above, the pressure sensor device 1602 depicted in FIG. 16 comprises an ASIC 1604 attached to the top side of a MEMS pressure sensing element 1622, as described above with respect to at least FIG. 2A. The ASIC 1604 is attached to the MEMS pressure sensing element 1622 by a fusion bond 1640, described above.

The ASIC 1604 has metallic bond pads 1608 on the top side 1610 of the ASIC 1604 that are connected by bond wires 1614 to lead frames 1612 that extend through the housing 1613. The bond wires 1614 are thin and fragile. The bond wires 1614 are therefore protected from breakage by a layer of a viscous gel 1616 that essentially fills the pocket 1606.

A layer of adhesive 1618 between the bottom 1620 of the backside MEMS pressure sensing element 1622 and the bottom 1624 of the pocket 1606 attaches the MEMS pressure sensing element 1622 to the bottom 1624 of the pocket 1606. The adhesive 1618 also provides a seal around an aperture 1628 through which a fluid can exert a pressure against the backside 1630 of a diaphragm 1632 formed in the pressure sensing element 1622. In yet another embodiment, a conformal coating layer is used to hold and protect the bond wire 1614.

FIG. 17 depicts a second and alternate embodiment of the pressure sensor module 1600 shown in FIG. 16. The pressure sensor module 1700 shown in FIG. 17 differs from the sensor module 1600 shown in FIG. 16 by only the use of a glass frit 1702 that provides a glass frit bond between the ASIC 1604 and the MEMS pressure sensing element 1622. The bond wires 1614 are protected by a viscous gel 1616.

Those of ordinary skill in the art will recognize that the foregoing description is for purposes of illustration only. The true scope of the invention is set forth in the following claims.

What is claimed is:

1. A pressure sensor device comprising:

a MEMS pressure sensing element having first and second sides with a flexible diaphragm and a Wheatstone bridge circuit on the first side;

a first integrated circuit comprising a substrate with first and second sides, electronic circuitry formed into a predetermined portion of the first side and a recess formed into the second side, the second side of the first integrated circuit being attached to the first side of the MEMS pressure sensing element, the recess of the first integrated circuit and the first side of the MEMS pressure sensing element defining a substantially evacuated cavity;

a first plurality of conductive vias formed into the first integrated circuit substrate such that the first plurality of vias extend through the substrate and electrically connect the Wheatstone bridge circuit of the MEMS pressure sensing element to the circuitry formed into the first side of the first integrated circuit; and

at least one of:

i) a layer of silicon dioxide between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of silicon dioxide forming a silicon fusion bond between the MEMS pressure sensing element and the integrated circuit; and an intermetallic bond formed between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element;

and

ii) a layer of glass frit located between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of glass frit forming a bond between the MEMS pressure sensing element and the first integrated circuit; and an electrically conductive protuberance between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element.

2. The pressure sensor device of claim 1, wherein the plurality of conductive vias are symmetrically distributed in the first integrated circuit substrate.

3. The pressure sensor device of claim 1, further comprising a second integrated circuit attached to the first side of the first integrated circuit, the second integrated circuit comprising a substrate with first and second sides and electronic circuitry formed into a predetermined portion of its first side.

4. The pressure sensor device of claim 3, further comprising a second plurality of conductive vias formed into the second integrated circuit substrate such that the second plurality of vias extend through the substrate of the second integrated circuit and electrically connect circuitry of the first integrated circuit to circuitry of the second integrated circuit.

5. The pressure sensor of device of claim 1, further comprising a pedestal attached to the second side of the MEMS pressure sensing element, the pedestal comprising an aperture, which is substantially aligned to the flexible diaphragm.

6. A pressure sensor device comprising:

a MEMS pressure sensing element having first and second sides with a flexible diaphragm and a Wheatstone bridge circuit on the first side;

a first integrated circuit comprising a substrate with first and second sides, electronic circuitry formed into a predetermined portion of the first side and a recess formed into the second side, the second side of the first integrated circuit being attached to the first side of the MEMS pressure sensing element, the recess of the first integrated circuit and the first side of the MEMS pressure sensing element defining a cavity;

a first plurality of conductive vias formed into the first integrated circuit substrate such that the first plurality of vias extend through the substrate and electrically connect the Wheatstone bridge circuit of the MEMS pressure sensing element to the circuitry formed into the first side of the first integrated circuit; and

at least one of:

i) a layer of silicon dioxide between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of silicon dioxide forming a silicon fusion bond between the MEMS pressure sensing element and the integrated circuit, the second side further comprising at least one trench formed to extend into the recess; and an intermetallic bond formed between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element;

and

ii) a layer of glass frit located between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of glass frit forming a bond between the MEMS pressure sensing element and the first integrated circuit; and an electrically conductive protuberance between at

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least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element, wherein the layer of glass frit is patterned to provide at least one media path through the layer of glass fit, the media path being configured to allow a predetermined fluid to pass through the media path and to the recess formed into the second side of the first integrated circuit.

7. The pressure sensor device of claim 6, wherein the plurality of conductive vias are symmetrically distributed in the first integrated circuit substrate.

8. The pressure sensor device of claim 6, further comprising a second integrated circuit attached to the first side of the first integrated circuit, the second integrated circuit comprising a substrate with first and second sides and electronic circuitry formed into a predetermined portion of its first side.

9. The pressure sensor device of claim 8, further comprising a second plurality of conductive vias formed into the second integrated circuit substrate such that the second plurality of vias extend through the substrate of the second integrated circuit and electrically connect circuitry of the first integrated circuit to circuitry of the second integrated circuit.

10. A pressure sensor module comprising:

a pressure sensor device comprising:

a MEMS pressure sensing element having first and second sides with a flexible diaphragm and a Wheatstone bridge circuit on the first side;

a first integrated circuit comprising a substrate with first and second sides, electronic circuitry formed into a predetermined portion of the first side and a recess formed into the second side, the second side of the first integrated circuit being attached to the first side of the MEMS pressure sensing element, the recess of the first integrated circuit and the first side of the MEMS pressure sensing element defining a substantially evacuated cavity; and

a first plurality of conductive vias formed into the first integrated circuit substrate such that the first plurality of vias extend through the substrate and electrically connect the Wheatstone bridge circuit of the MEMS pressure sensing element to the circuitry formed into the first side of the first integrated circuit;

a housing having a pocket that encloses the pressure sensor device and a pressure port configured to allow a predetermined fluid to apply pressure to the diaphragm; and

a lead frame that extends from an electrical contact on the first side of the first integrated circuit through the housing, the electrical contact on the first side of the first integrated circuit comprising at least one of an electrically conductive protuberance and an electrically conductive adhesive.

11. The pressure sensor module of claim 10, further comprising a layer of adhesive between the first integrated circuit and an interior surface of the pocket, the layer of adhesive being configured to mount the pressure sensor device to an interior surface of the pocket and substantially cover the electrical contact on the first side of the first integrated circuit.

12. The pressure sensor module of claim 10, wherein the MEMS pressure sensing element has a plurality of electrical contacts on its first side, the pressure sensor device further comprising:

a layer of silicon dioxide between the first side of the MEMS pressure sensing element and the second side of

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the first integrated circuit, the layer of silicon dioxide forming a silicon fusion bond between the MEMS pressure sensing element and the first integrated circuit; and

an intermetallic bond formed between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element.

13. The pressure sensor module of claim 10, wherein the MEMS pressure sensing element has a plurality of electrical contacts on its first side, the pressure sensor device further comprising:

a layer of glass frit located between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of glass frit forming a bond between the MEMS pressure sensing element and the first integrated circuit; and

an electrically conductive protuberance between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element.

14. The pressure sensor module of claim 10, wherein the plurality of conductive vias are symmetrically distributed in the first integrated circuit substrate.

15. The pressure sensor module of claim 10, further comprising a second integrated circuit attached to the first side of the first integrated circuit, the second integrated circuit comprising a substrate with first and second sides and electronic circuitry formed into a predetermined portion of its first side.

16. The pressure sensor module of claim 15, further comprising a second plurality of conductive vias formed into the second integrated circuit substrate such that the second plurality of vias extend through the substrate of the second integrated circuit and electrically connect circuitry of the first integrated circuit to circuitry of the second integrated circuit.

17. The pressure sensor module of claim 10, further comprising a pedestal attached to the second side of the MEMS pressure sensing element, the pedestal comprising an aperture, which is substantially aligned to the flexible diaphragm.

18. A pressure sensor module comprising:

a pressure sensor device comprising:

a MEMS pressure sensing element having first and second sides with a flexible diaphragm and a Wheatstone bridge circuit on the first side;

a first integrated circuit comprising a substrate with first and second sides, electronic circuitry formed into a predetermined portion of the first side and a recess formed into the second side, the second side of the first integrated circuit being attached to the first side of the MEMS pressure sensing element, the recess of the first integrated circuit and the first side of the MEMS pressure sensing element defining a substantially evacuated cavity; and

a first plurality of conductive vias formed into the first integrated circuit substrate such that the first plurality of vias extend through the substrate and electrically connect the Wheatstone bridge circuit of the MEMS pressure sensing element to the circuitry formed into the first side of the first integrated circuit; and

at least one of:

i) a layer of silicon dioxide between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of silicon dioxide forming a silicon fusion bond between the MEMS pressure sensing element and the integrated circuit; and an intermetallic bond formed between at

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least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element;

and

ii) a layer of glass frit located between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of glass frit forming a bond between the MEMS pressure sensing element and the first integrated circuit; and an electrically conductive protuberance between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element;

a housing having a pocket that encloses the pressure sensing device and a pressure port configured to allow a predetermined fluid to apply pressure to the diaphragm;

a lead frame that extends from inside the pocket through the housing;

a bond wire that extends from an electrical contact on the first side of the first integrated circuit to the lead frame; and

an adhesive layer located between the second side of the MEMS pressure sensing element and an interior surface of the pocket through which the pressure port is formed, the adhesive layer surrounding and sealing the pressure port to the second side of the MEMS pressure sensing element.

19. The pressure sensor module of claim 18, further comprising a layer of gel inside the pocket and substantially covering the pressure sensor device.

20. The pressure sensor module of claim 18, further comprising a conformal coating over the pressure sensor device, the bond wire and at least part of the lead frame.

21. The pressure sensor module of claim 18, wherein the plurality of conductive vias are symmetrically distributed in the first integrated circuit substrate.

22. The pressure sensor module of claim 18, further comprising a second integrated circuit attached to the first side of the first integrated circuit, the second integrated circuit comprising a substrate with first and second sides and electronic circuitry formed into a predetermined portion of its first side.

23. The pressure sensor module of claim 22, further comprising a second plurality of conductive vias formed into the second integrated circuit substrate such that the second plurality of vias extend through the substrate of the second integrated circuit and electrically connect circuitry of the first integrated circuit to circuitry of the second integrated circuit.

24. The pressure sensor module of claim 18, further comprising a pedestal attached to the second side of the MEMS pressure sensing element, the pedestal comprising an aperture, which is substantially aligned to the flexible diaphragm.

25. A pressure sensor module comprising:

a pressure sensor device comprising:

a MEMS pressure sensing element having first and second sides with a flexible diaphragm and a Wheatstone bridge circuit on the first side;

a first integrated circuit comprising a substrate with first and second sides, electronic circuitry formed into a predetermined portion of the first side and a recess formed into the second side, the second side of the first integrated circuit being attached to the first side of the MEMS pressure sensing element, the recess of

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the first integrated circuit and the first side of the MEMS pressure sensing element defining a cavity; a first plurality of conductive vias formed into the first integrated circuit substrate such that the first plurality of vias extend through the substrate and electrically connect the Wheatstone bridge circuit of the MEMS pressure sensing element to the circuitry formed into the first side of the first integrated circuit; and

at least one of:

i) a layer of silicon dioxide between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of silicon dioxide forming a silicon fusion bond between the MEMS pressure sensing element and the integrated circuit, the second side further comprising at least one trench formed to extend into the recess; and an intermetallic bond formed between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element;

and

ii) a layer of glass frit located between the first side of the MEMS pressure sensing element and the second side of the first integrated circuit, the layer of glass frit forming a bond between the MEMS pressure sensing element and the first integrated circuit; and an electrically conductive protuberance between at least one of the conductive vias and an electrical contact on the first side of the MEMS pressure sensing element wherein the layer of glass frit is patterned to provide at least one media path through the layer of glass frit, the media path being configured to allow a predetermined fluid to pass through the media path and to the recess formed into the second side of the first integrated circuit;

a housing having a pocket that encloses the pressure sensing device and a pressure port configured to allow a predetermined fluid to apply pressure to the diaphragm;

a lead frame that extends from inside the pocket through the housing;

a bond wire that extends from an electrical contact on the first side of the first integrated circuit to the lead frame; and

an adhesive layer located between the second side of the MEMS pressure sensing element and an interior surface of the pocket through which the pressure port is formed, the adhesive layer surrounding and sealing the pressure port to the second side of the MEMS pressure sensing element.

26. The pressure sensor module of claim 25, wherein the plurality of conductive vias are symmetrically distributed in the first integrated circuit substrate.

27. The pressure sensor module of claim 25, further comprising a second integrated circuit attached to the first side of the first integrated circuit, the second integrated circuit comprising a substrate with first and second sides and electronic circuitry formed into a predetermined portion of its first side.

28. The pressure sensor module of claim 27, further comprising a second plurality of conductive vias formed into the second integrated circuit substrate such that the second plurality of vias extend through the substrate of the second integrated circuit and electrically connect circuitry of the first integrated circuit to circuitry of the second integrated circuit.